HIGHWAY RESEARCH RECORD

Number 421

Remote Sensing for Highway Engineering

11 reports

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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Remote Sensing for Highway Engineering

11 reports
prepared for the
51st Annual Meeting

Subject Areas

21	Photogrammetry
22	Highway Design
53	Traffic Control and Operations
61	Exploration-Classification (Soils)

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FOREWORD

The series of remote-sensing papers in this RECORD describes current research and expands the state of the art regarding the use of aerial reconnaissance techniques for acquisition and application of data useful in planning, design, construction, maintenance, and operation of highway facilities. Synopses of individual papers are contained in the Introduction.

INTRODUCTION

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Harold T. Rib, Federal Highway Administration, U.S. Department of Transportation

The variety of remote-sensing systems and analysis techniques that are available today and the high costs connected with their use present a dilemma to highway engineers. Questions are being asked: Which sensor-analysis combinations are best for specific engineering problems? Does the information obtained warrant the additional cost? For example, one can select from a variety of sensor systems including mapping cameras; multiband cameras or clusters of cameras using a variety of film-filter combinations; infrared, radar, and multispectral scanners; microwave radiometers and scatterometers; laser profilers; and others. Data extraction and analysis techniques available include color enhancement, density slicing, image quantitizing, microdensity scanning, and pattern-recognition techniques using analog, digital, or hybrid computer systems.

Some earlier remote-sensing studies were published in Highway Research Board Special Report 102 and Highway Research Record 319. This series of papers on remote sensing expands the current state of the art regarding the means of acquisition of data, shows the latest research activities, and presents some applications of remote sensing for highway engineers and others.

Dwelling and Burchell present a review of side-look airborne radar (SLAR) and discuss its uses and limitations as a reconnaissance tool. When the SLAR mosaic is used as a synoptic view of the terrain, gross patterns and detailed structure are presented. The authors show that a photo interpreter with minimum skills and training can acquire useful data. Drainage data are measured as directly from SLAR as from 1/24,000-scale maps. Coarse-resolution SLAR produces discrimination of lithological features that can be traced out, even some features previously not known. Dual-polarization modes of SLAR place a definition of soil mositure within the grasp of the engineer. One important note is that SLAR flight mission must be carefully planned for best results. This is best done when one knows SLAR capabilities and limitations.

Stingelin presents the limitations of airborne infrared imagery in civil engineering practice and shows that the imagery may be expected to yield marginal results in differentiation of lithological and soil conditions; explorations for shallow aquifers in humid climatic zones; detection of surface voids, gases, or deep mine fires; exploration for mineral and petroleum resources; and investigation of water quality. The author noted that the best results are obtained when both thermal infrared and aerial photography are studied in conjunction with each other. Digital processing of infrared signals and computer analysis as information retrieval systems have real promise.

Lowe and Wilson show the features and limitations of multispectral scanning systems resulting from recent developments and improvements in optical-mechanical technology. The authors believe that the potential for multispectral sensing is in surveying large areas in a short time when there is need to quickly classify the earth's features by their spectral characteristics. The multispectral scanner observes only surface phenomena. Environmental effects such as atmosphere, sun angle, snow, moisture, and wind limit the accuracy of the interpreted data. Instrument effects also limit the utility of this mode of remote sensing. Field calibration measurements, particularly field spectrometry, are needed to enhance the accuracy of separating target categories. However, there appears to be a real advantage for automatically processing data acquired from large areas, and the multispectral scanner approach provides a potential means of doing this.

The most extensive remote-sensing research program in the highway field was initiated in 1967 by the Federal Highway Administration. This program coordinates

the efforts of FHWA and a state highway department. The results obtained to date from some of the studies in this cooperative program are contained in papers by Rib, Noble, Stallard, West, Wagner, and Dedman and Culver.

Rib describes the background and scope of the cooperative program, the participants in the program, and the present status.

Noble and Stallard describe 2 of the test sites and the cooperative efforts by the respective state highway departments and present some of the results obtained. Noble found that thermal infrared imagery (8.0 to 13.5 μm) taken at night enables the engineer to detect and delineate water-soil boundaries; drainageways moving water sometimes are obscure on other imagery. Combining aerial photography and thermal infrared imagery was the best procedure. The nighttmite-daytime thermal imagery combined with aerial photographs provided a guide to locating subsurface cavities.

Stallard observed that the interpretation of color aerial photography provided the best means of mapping soils, and combining color aerial photography with thermal infrared (8 to 14 μm) nighttime imagery provided evidence for detection, evaluation, and mapping of engineering soil groups. Color infrared and color photography provided similar information, but additional contrasts of the infrared revealed vegetation changes. Other investigators have made similar findings.

West and Wagner describe their research efforts in developing computer analysis techniques for accomplishing soil mapping. Their observations show that, with multispectral imagery and LARS computer techniques, a tremendous volume of data can be analyzed and classifications can be made with 90 percent accuracy. Some channels of multispectral data are better than others; i.e., the best channels for mapping engineering soils by means of multispectral scanner techniques include the following μm bands: 0.44 to 0.46, 0.58 to 0.62, 1.00 to 1.40, and 2.60. Objects that can be discriminated are vegetation types, water, roads, rooftops, quarries, and wet soil areas where soil cover over bedrock is thin. There is a physical limit to the number of data classifications because of a limited memory; the limit encountered in this study was 43 classes. The study developed a new approach to dealing with large amounts of data. The cluster analysis approach shows promise and is now being tested.

Wagner shows that useful and relatively accurate soil maps may be developed from computer recognition of multispectral data. To provide an operational system requires knowledge of what soil parameters determine the spectral signatures recognized by the computer and what surface spectral differences are required to delineate soil mapping classes. A priori soil data are required for programming the computer. There is research under way for developing the use of a much broader range of the electromagnetic spectrum than has currently been estabiished. The area of computer-programmed soil mapping from multispectral data has real promise.

Dedman and Culver describe the efforts by another contractor to evaluate the use of a special airborne sensor system for detecting subsurface cavities. The microwave radiometer survey technique has potential for detecting voids. Known voids occur where radiometric isotherms predict them to be, but additional field surveys are necessary to positively prove the potential of airborne radiometry in locating the position of the voids.

The results reported in these 6 papers, although not conclusive, clearly demonstrate the potential value of some remote-sensing systems and analysis techniques in locating highway problem soil areas. The areas where further research efforts are required are identified.

The next 2 papers demonstrate some applications of remote sensing.

Treiterer shows the techniques and instrumentation for using infrared sensing to improve traffic safety and capacity. A non-self-contained longitudinal infrared sensing device has been adopted for target identification within traffic lanes; however, the source-sensor system needs further development to minimize target identification errors.

Kiefer indicates that there is an optimum period of time during the year for procuring aerial photographs for photo interpretation of soils; for example, in Wisconsin it is May 1 to June 15 and September 1 to 30. Thermal imagery has promise in soil mapping and evaluating.

SIDE-LOOK RADAR: ITS USES AND LIMITATIONS AS A RECONNAISSANCE TOOL

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Charles Burchell, Aerospace Division, Westinghouse Electric Corporation

The short-time imaging of Darien Province, Panama, and the subsequent analysis of the imagery by geoscientists indicated a great potential for side-look radar as a reconnaissance tool in many areas of earth study, particularly where climatic conditions are adverse to aerial photography. Evaluation of additional radar imagery from other environments has demonstrated the reality of this potential. Rapid, all-weather imaging and the resulting synoptic, ground-range presentation point to radar as a valuable first-look tool. From acquisition-scale imagery or from an easily assembled mosaic, relief and slope data can be obtained; drainage patterns and basins can be accurately defined; and bedrock geology, surface material, and vegetation studies can be conducted. Structural configuration of bedrock and fracture patterns can also be determined with a high degree of accuracy. Utilizing the dual-polarization capability of radar permits, in addition, the qualitative determination of soil moisture content and may provide added vegetation data. The characteristics of the radar system and the factors that influence radar return should be known by the user, not only for interpretation but also for mission planning. The ability of side-look radar to rapidly acquire data under all weather conditions offsets the limitation of the relatively high cost for small-area surveys and a resolution capability less than that of the aerial photograph. The prime value of radar is realized from its synoptic presentation in the early stages of a survey.

•IN 1967, four complete coverages of a 17,000 square kilometer area in Darien Province, Panama, were achieved in approximately 6 hours of imaging time during a 6-day period in a heavily cloud-shrouded region. This mapping (Fig. 1) established side-look airborne radar (SLAR) as a geoscience tool of the future. A similar dramatic use of this non-weather-dependent tool was recently made during the history-making voyage of the tanker Manhattan when radar was revealed as the most effective sensor utilized in determining ice conditions in the Arctic waters. Little doubt has been left as to the value of SLAR where climatic conditions are adverse to aerial photography. During a period of 15 years of continuous effort in Panama, only 40 percent of the area imaged by SLAR had ever been photographed. A large percentage of the continent's surface is cloud-covered much of the time (Fig. 2); therefore, the value of a sensor that is essentially non-weather-dependent can easily be recognized. Rapid data acquisition is facilitated through the continuous imaging of swaths of the earth's surface as wide as 80 km (AN/APQ-69) and through the utilization of high-speed jet aircraft (YEA-3A) as platforms. Although currently available systems do not approach these maxima, the characteristic wide-swath, continuous imaging of SLAR results in rapid data acquisition compared to that by conventional photography.

IMAGE GENERATION AND PRESENTATION FORMAT

The wide-swath continuous imaging of SLAR results in a synoptic presentation that has proved to be especially valuable in the revelation of gross and subtle features often overlooked in photographic presentations (2). This arises from the presentation

Figure 1. Radar mosaic of Darien Province, Panama.

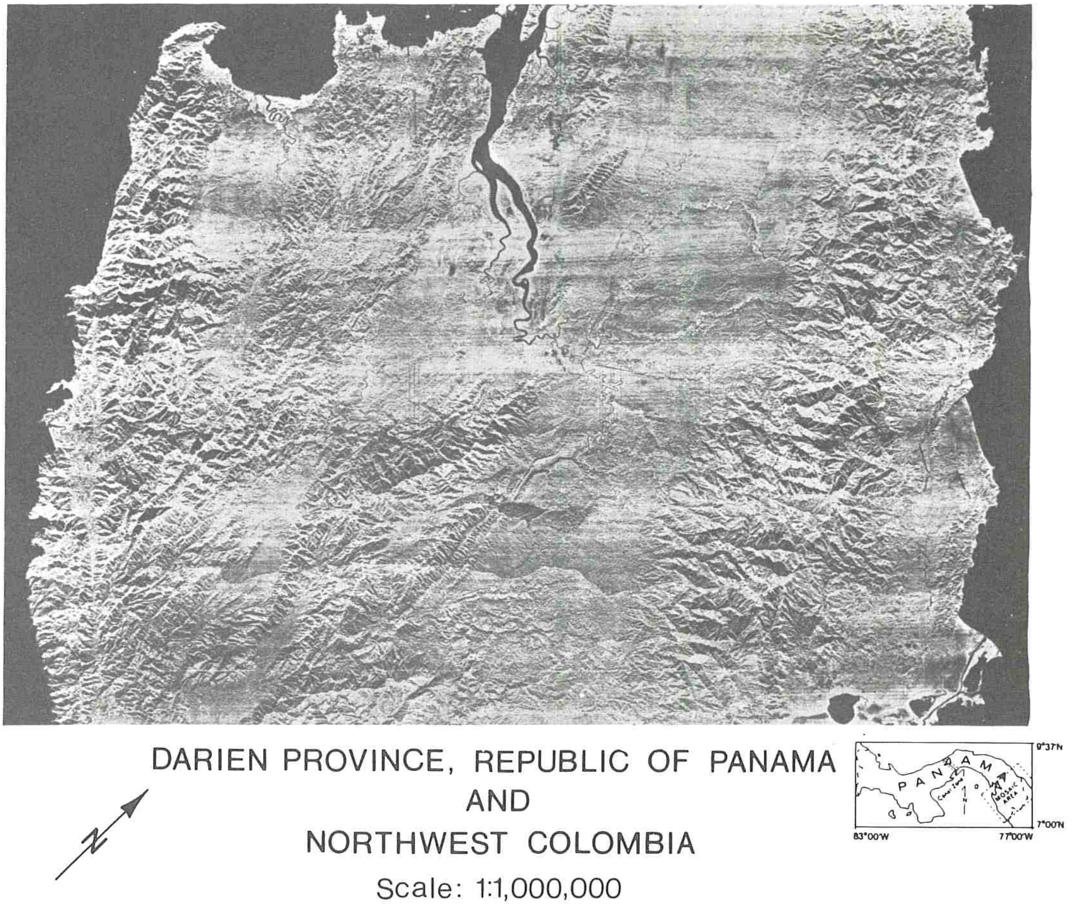
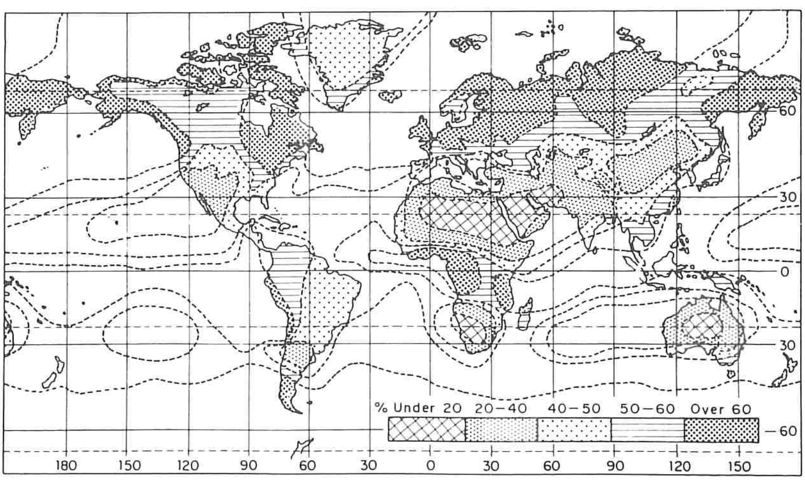


Figure 2. Mean annual cloud cover for the world in percentage of sky covered (Rumney, 1968).



on SLAR imagery of a large area in a small format so that the eye integrates what may be seemingly unrelated features in larger format. The degradation of often distracting detail due to a SLAR resolution somewhat less than that of the photograph is also a contributing factor to the dramatic presentation of gross patterns and features.

Although improvement in resolution can be (and on some classified radars has already been) achieved, the increase in detail distracts from the presentation of gross patterns. Although much detail is revealed through the magnification of radar imagery with a ±50-ft resolution as currently produced, realistically from the cost point of view, radar cannot be viewed as a practical tool for the acquisition of detailed surface information in small areas except when essentially real-time data are required and no other sensor is capable of data collection (for example, during the voyage of the Manhattan through Arctic waters).

To suggest that radar is of greatest value as a reconnaissance or first-look tool does not imply that radar imagery lacks in geometric fidelity. Imaging systems currently operating commercially produce imagery that conforms to mapping standards established by the U. S. Geological Survey. Several as yet classified systems achieve even greater geometric fidelity; however, distance can be measured with greater accuracy on currently produced imagery than on conventional aerial photographs. Thus SLAR, offering rapid, broad coverage within acceptable limits of accuracy, merits serious consideration as a tool for updating highway and drainage networks and vegetation distribution on outdated topographic maps.

Radar imagery of areas whose sizes exceed SLAR's swath-width capability can be easily and effectively mosaicked (Fig. 3). Figure 4 shows how the difficulties of mosaicking slant-range imagery (horizontal scale normal to flight line compressed in the near range) can be overcome if the return signal is recorded in a ground-range format (horizontal scale equal in all directions). Geologic trends not previously identified have been revealed not only in the radar mosaics of Panama but also in the mosaic of Massachusetts, an area previously subjected to intensive surface and photographic investigation. The versatility of SLAR imagery has best been demonstrated by Wing (17) in his expansion of an earlier study of Darien Province by MacDonald (8). Utilizing the radar mosaic, as well as acquisition scale imagery often under magnification, resulted in the revelation not only of gross patterns but also of considerable detailed structure.

EASE OF INTERPRETATION

To the potential user of SLAR imagery, normally 2 questions immediately come to mind: (a) How much training is necessary for effective interpretation? and (b) Is stereoscopic coverage available? Although the energy recorded (and transmitted) by the radar is in a different electromagnetic spectrum frequency range from that of solar energy and the controlling factors for the interaction of any given target are different with this energy from those with light, the similarity of the film records is obvious. Techniques of interpretation are also similar. A skilled photo interpreter need only become familiar with parameters that control radar return, understand their effect on the return signal, and recognize the effect of the side-looking configuration of the sensor on the geometry of the return signal. As in photography, variations in tone, texture, shape, and pattern signify variations in surface features and structures. Groups of potential interpreters, not necessarily skilled in photo interpretation, have been trained thoroughly in 4 or 5 days, and small groups or individual photo interpreters can be trained in 1 or 2 days.

In areas of moderate to high relief, the characteristic shadowing of the side-looking system reveals relative relief to the unaided eye. Stereoscopic coverage is feasible (Fig. 5), and methods for producing contour information are under study. The 60 percent overlap not only ensures the 3-dimensional stereoscopic display but also ensures the placement of each terrain unit in near and far range positions. Therefore, in areas of high relief the excessive shadowing that might mask large areas in the far range is reduced to a minimum in the near range; and in areas of low relief subtle features that might escape detection in the near range are accentuated through shadowing of the image in the far range (Fig. 6).

Figure 3. Kentucky test range mosaic (ground-range radar display) containing 3 horizontal splice lines.

Figure 4. Comparison of geometry of ground-range and slant-range imagery (8).

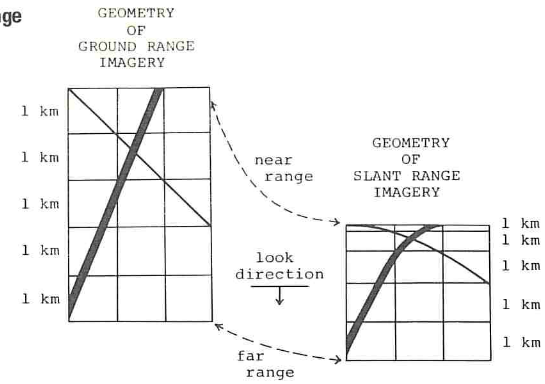


Figure 5. Radar-stereo pair.

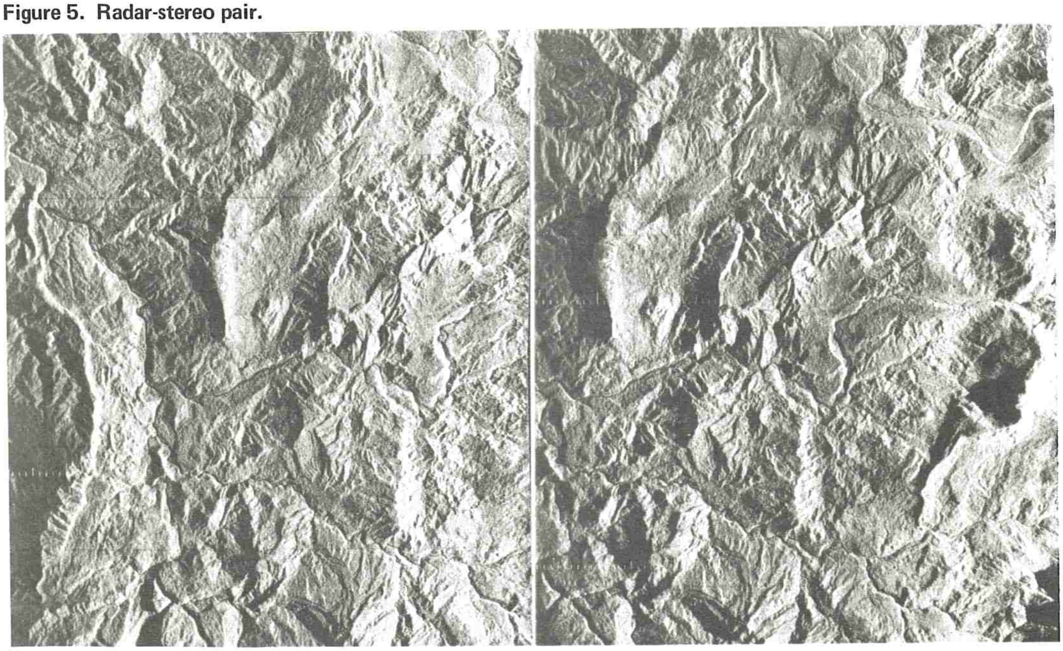
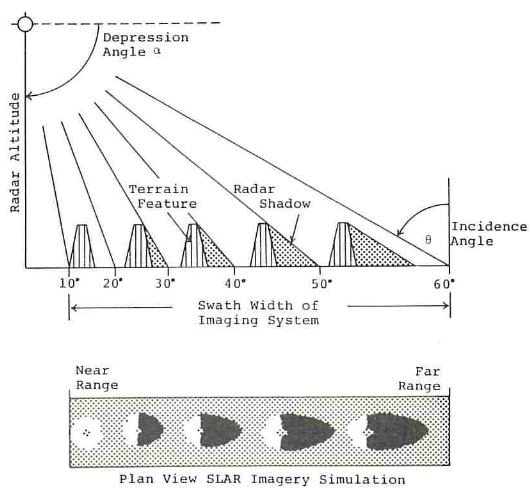


Figure 6. Shadowing characteristics of SLAR imaging systems.



SURFACE CONFIGURATION AND HYDROLOGIC DATA CONTENT

Quantitative slope, not qualitative relief, data are desired in most engineering or geoscience studies. Interferometer techniques have been used with good results for the preparation of topographic maps (Fig. 7), although the cost of data reduction is essentially prohibitive. Recognition of the value of this technique has prompted additional research and development with anticipation of the utilization of this technique in mapping.

For the determination of spot elevations (6, 13), simple techniques of shadow analysis of single radar images may be utilized. However, both methods require knowledge of aircraft elevation and slant distance to target and are based on the assumption that the radar shadow is falling on a flat surface, a condition not often realized. McCoy (14), utilizing a knowledge of the range of depression angles across an image, obtained an expression of slope in the zone where the radar beam grazes the slope and generates no shadow. However, if a slope is imaged twice along parallel flight paths from the opposite or the same direction, the slope angle can be accurately determined theoretically as a function of depression angles and slant-range measurements (which may be easily calculated from a ground-range display). However, practical accuracy requires careful selection of identical points on both images, accurate measurements, and accurate determination of depression angles. Such measurements are time-consuming and impractical for regional studies. Nonetheless, with stereoscopic coverage, an altimeter profile, and a potential of spot elevation and slope determinations, reasonable estimations of volumes of cuts or fills can be made from ground-range imagery.

Drainage basin data are desirable at the reconnaissance level of investigation. Radar imagery as a tool for drainage basin analysis was evaluated by McCoy (14), who, primarily utilizing AN/APQ-97 imagery in the early slant-range format (Fig. 8), concluded that the drainage area, basin perimeter, bifurcation ratio, average length ratio, and circularity ratio could be measured directly from the imagery with little difference from values derived from 1:24,000 USGS topographic quadrangles. Stream numbers, lengths of streams, and drainage density show sufficiently consistent differences between map and radar-derived values to permit, by use of an appropriate equation, the conversion of radar-imagery values to map values. Because of the consistency of difference, use of the conversion factor reduces the stream length and related data error to acceptable limits for hydrologic reconnaissance studies. The use of such a factor is necessitated by the loss of low-order stream detail on the radar imagery. A not-to-be-overlooked source of error in areas of high relief is shadowing that may obscure portions of a given drainage basin, but positioning of such areas in the near range of the image (11) or imaging the areas from 2 directions can nullify the potential loss. Inasmuch as McCoy's investigation was conducted by the use of a slant-range imagery, even greater fidelity in a ground-range presentation should be expected.

GEOLOGIC DATA CONTENT

As a tool for geologic data collection, radar has a well-documented capability, a capability largely attributable to synoptic presentation, suppression of distracting detail, reduction of resolution, and radar shadowing. An early study of imagery (2) covering the Boston Mountains of Arkansas (Fig. 9) revealed a pronounced north-south fracture pattern that had not been previously detected through detailed aerial photograph evaluation and field study. A low elevation overflight of the area after the pattern was detected on radar imagery showed the alignment of discrete segments of streams that had developed in zones of concentrated fracturing, zones apparently detectable only under the conditions stated above.

A more recent investigation (18) of radar imagery in the Burning Springs, West Virginia, area resulted in sharper definition of fracture orientations that could be achieved through study of aerial photographs or field measurements. Weathering along joints had influenced stream development, and the trends of fractures were reflected in well-defined topographic features. The accurate definition of diversely oriented and developed fracture patterns and the identification of major zones of weakness or movement may prove extremely valuable to the engineer, especially in the preliminary planning stages of projects requiring the quarrying or removal of large quantities of rock

Figure 7. Topography of Harper's Ferry mapped by radar data (left) and by photogrammetric techniques (right).

UNCLASSIFIED

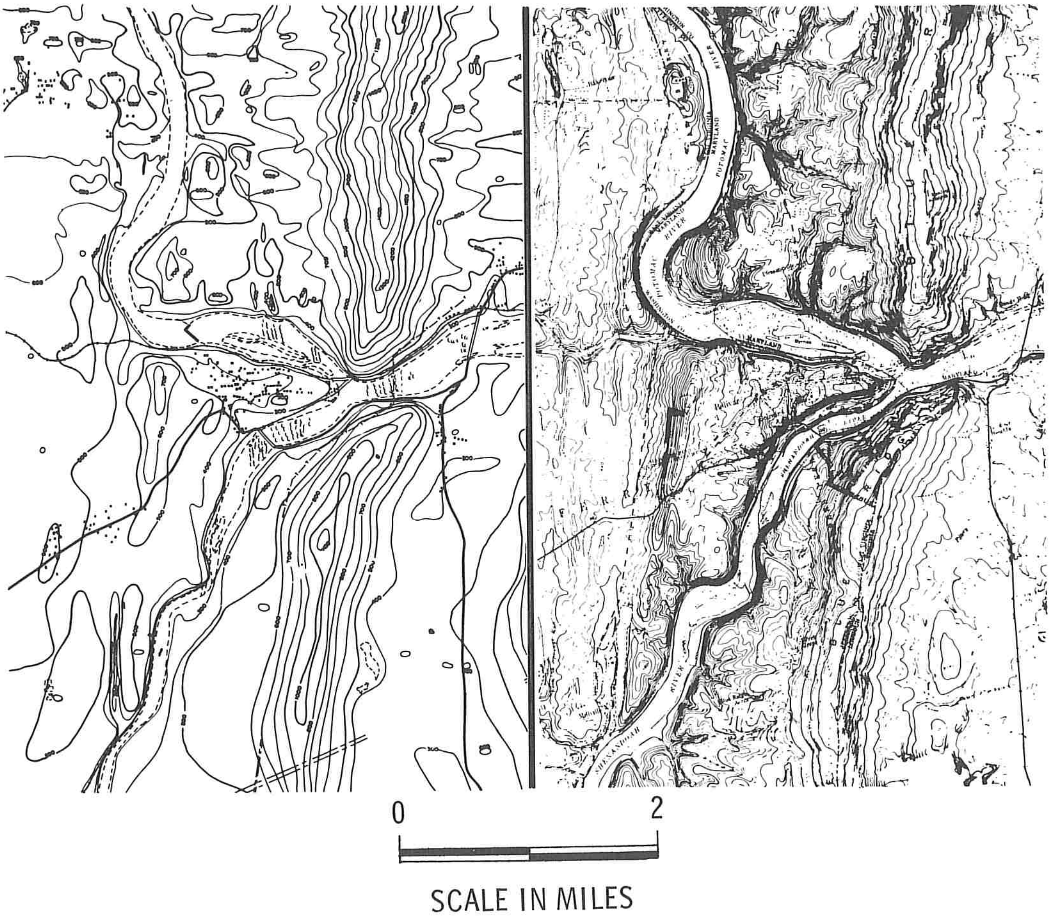


Figure 8. Drainage maps derived from topographic map and radar imagery.

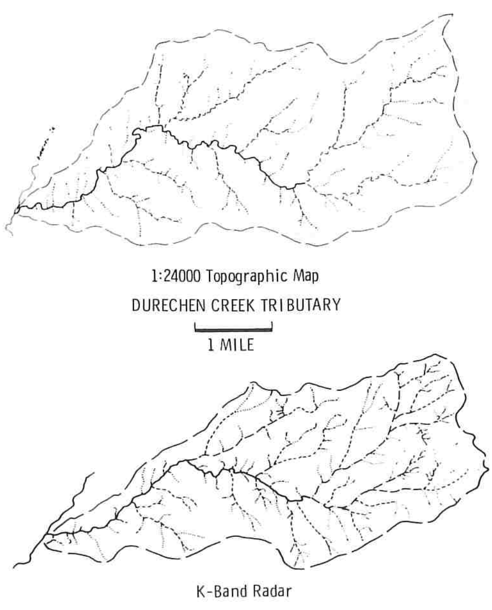
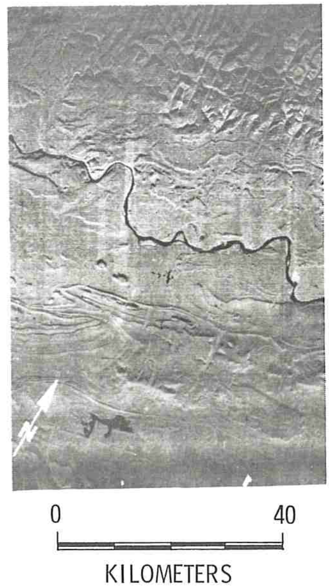


Figure 9. AN/APQ-69 radar imagery showing north-south linear trends in the Boston Mountains.



materials or in the preliminary route selection through unmapped areas in which ground reconnaissance is not feasible.

As on aerial photographs, lithologies are separable on the basis of tonal, textural, pattern, and shape characteristics. For example, in the evaluation of imagery of Panama, limestones were identified by the development of karst topography, and igneous intrusions and lava flows were identified on the basis of shape (Fig. 10). Most rock units in this environment could be traced on the basis of topographic expression. In less intensely vegetated areas, one might rely more heavily on flora distribution and topographic fracture texture patterns, both of which may be directly influenced by rock type. Mapping on the basis of residual soils is not feasible at this time, unless a correlation between soil and vegetation can be identified.

With the identification and separation of lithologic units, the definition of structure offers no difficulty. The degree to which units can be isolated and minor structures identified is to some extent a function of resolution. On classified high-resolution radar imagery of the Ouachita Mountains, a more detailed separation of lithologic units and easier identification of small-scale structure could be made than on imagery from other, coarser resolution radars. However, with improvement of resolution comes an increase in distracting detail so that the definition of minor features is at the expense of major (4).

DUAL-POLARIZATION RADAR: A TOOL WITH POTENTIAL

The potential value of simultaneously recording like- and cross-polarized return was early demonstrated by Dellwig and Moore (5), who made a preliminary evaluation of anomalously depolarized return signals in the Pisgah Crater area. About the same time, Morain (15) noted that the relatively uniformly textured and even-toned return from the vegetation on the like-polarized return was shown to be separable into areas of variable tones on the cross-polarized return. The degree of depolarization was directly related to vegetation type, the area boundaries paralleling those defined by the U.S. Forest Service map. More recently, McCauley (personal communication) has established a relation between the geometry of the surface of some volcanic rocks and sandstones and the cross-polarized return signal, suggesting that anomalously low cross-polarized return is dominated by specular reflection from planar rock surfaces that are large in comparison with the wavelength of the incident radar. Although of undetermined value at present, some potential for future utilization of the cross-polarized return in further discrimination of rock and soil (and vegetation) types is indicated.

A currently better defined capability of dual-polarized radar is in the revelation of a qualitative estimate of soil moisture content (Fig. 11). MacDonald and Waite (12), utilizing like- and cross-polarized return, discriminated between wet and dry areas in the near range in portions of the Gulf Coast with sufficient accuracy to warrant further investigation of this capability. The high degree of correlation between the electrical properties of soil and soil moisture content indicates that in a like manner areas of permafrost in the Arctic regions could be easily delineated. Definition of soil moisture content having been achieved with Ka-band imagery suggests an even greater potential for soil moisture content determination for the as yet untested long wavelength radars.

RECOMMENDATIONS FOR USE

As in any sensor utilization, the maximum value from radar imagery can be realized only as a result of efficient mission planning with full understanding of the characteristics, capabilities, and limitations of the sensor. The film record of radar return may tend to be misleading because of its similarity to an areal photograph taken with oblique sun angle. However, the response of a surface to radar is not the same as that to light; a host of parameters, some not yet fully evaluated, interact to influence the radar return signal. System parameters include resolution, polarization, depression angle, aircraft elevation, and orientation of flight lines relative to the potential target's structure. Surface parameters of importance are dielectric constant

Figure 10. Radar imagery of eastern Panamanian isthmus showing (left) northwestern Darien range—(d) anticlinal fold, (e) synclinal fold, (f) valley in Upper Eocene shale, and (g) karst topography developed on Lower-Middle Oligocene carbonates—and (right) Chiman coastal area—(a) igneous plug, (b) caldera ring, (c) igneous dikes, (d) caldera, and (e) north-south striking fault (18).

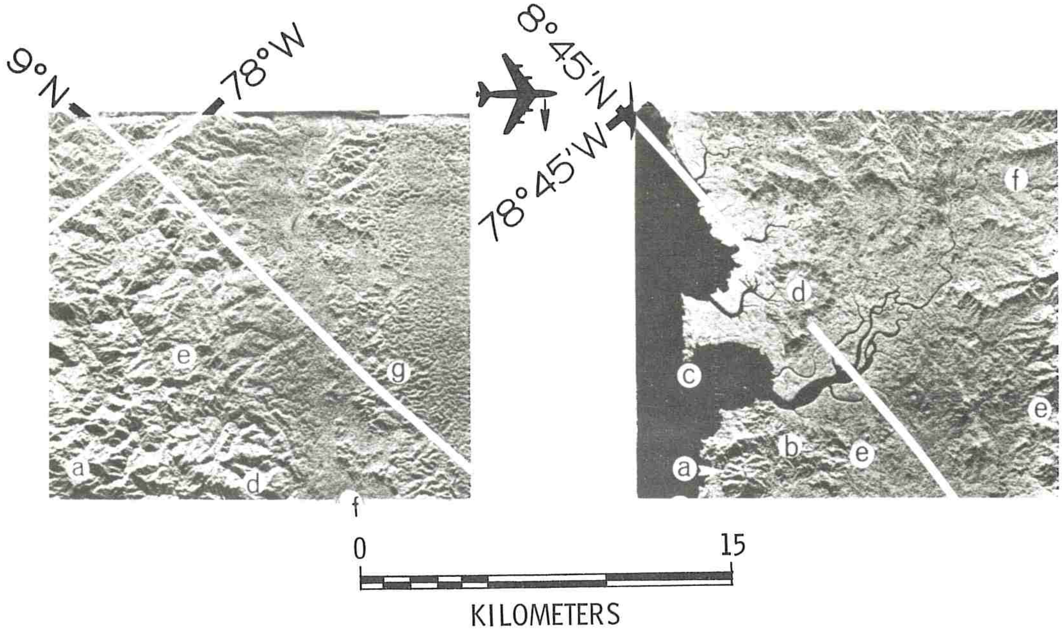
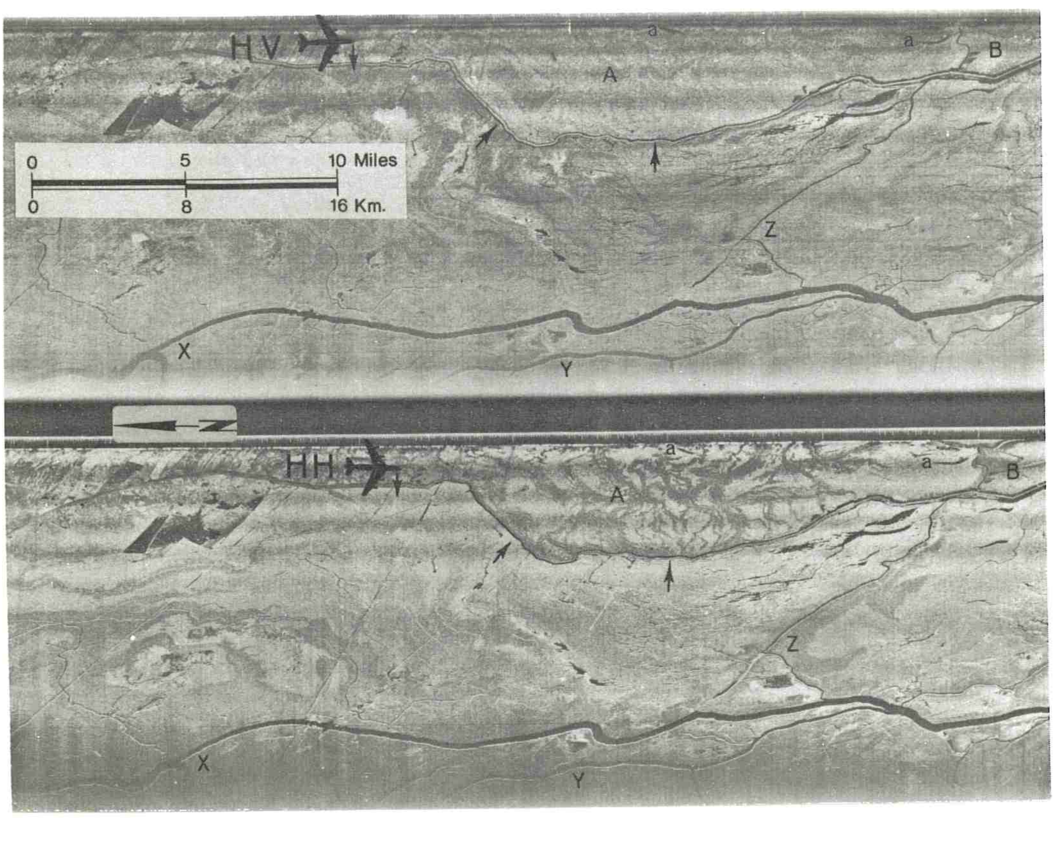


Figure 11. Like-polarized (HH) and cross-polarized (HV) radar imagery along Atchafalava River, southwest of Baton Rouge, Louisiana (light-toned areas on HH image are true swamps, and dark-toned areas are better drained).



of surface materials (including moisture content), surface configuration (roughness) relative to wavelength, and relief relative to the depression angle.

Systems available to users at this time are high-frequency systems (K- and X-band) with which no significant penetration should be expected. Limited studies show that, with the long wavelength radars (P-band), some penetration will be obtained even though the effect is somewhat clouded by the smoothing of surfaces (resulting in low return) that appear rough to short wavelength radars (1). However, an important future potential is indicated. Resolution is at present limited in nonclassified systems at approximately 30 ft. Whether improvement in resolution would be desirable depends on the nature of the survey, as, for example, a reconnaissance or "first-look" survey (for which radar is best suited) that requires no better resolution than that provided by existing commercial systems. Transmission polarization can be controlled in some systems although the effect is not fully understood. However, simultaneous recording of like- and cross-polarized return has proved to be advantageous to a limited degree not only in the discrimination of vegetation, soil moisture, and rocks but also in the definition of cultural features such as transportation and communication nets (7).

Depression angle is normally fixed. Ideally, low-relief features in flat terrain are most pronounced at near grazing angle (far range) and, if linear, oriented parallel to the direction of flight (10). In areas of high relief, however, the maximum data content is in the near range where shadowing is reduced to a minimum.

Although depression angle is not variable, optimum coverage of a given terrain unit can be obtained by variations in elevation (11). Shadow zones can be completely eliminated if an area is looked at from 2 different directions. Flight-line orientation is especially critical in low-relief terrain. Parallelism of the flight line with the orientation of linear topographic trends maximizes the display; the expression of such features diminishes as the look direction approaches parallelism with the linear trend.

Surface parameters, are, of course, not subject to control. Maximizing return must result primarily from system parameters adjusted insofar as possible and, if feasible, flights conducted during periods of vegetation defoliation.

Radar must be considered primarily a reconnaissance tool; it is of great value in planning a Pan American highway where aerial photography and ground surveys are not feasible but of very little value in planning highway networks within the limits of the 48 states. However, the potential of broad-scale, rapid, non-weather-dependent data acquisition suggests radar as an ideal tool for updating existing maps and for rapidly assessing communication network damage resulting from natural catastrophes such as floods, hurricanes, and earthquakes.

REFERENCES

1. Dellwig, L. F. An Evaluation of Multifrequency Radar Imagery of the Pisgah Crater Area, California. Modern Geology, Vol. 1, 1969, pp. 65-73.
2. Dellwig, L. F., Kirk, J. N., and Walters, R. L. The Potential of Low Resolution Radar Imagery in Regional Geologic Studies. Jour. Geophysical Res., Vol. 71, 1966, pp. 4995-4998.
3. Dellwig, L. F., MacDonald, H. C., and Kirk, J. N. Technique for Producing a Pseudo-Three Dimensional Effect With Monoscopic Radar Imagery. Photogrammetric Eng., Vol. 36, 1970, pp. 987-988.
4. Dellwig, L. F., and McCauley, J. R. Evaluation of High Resolution X-Band Radar in the Ouachita Mountains. Center for Research, Inc., Univ. of Kansas, Lawrence, Tech. Rept. 177-21, 1971, 8 pp.
5. Dellwig, L. F., and Moore, R. K. The Geological Value of Simultaneously Produced Like- and Cross-Polarized Radar Imagery. Jour. Geophysical Res., Vol. 71, 1966, pp. 3597-3601.
6. Levin, D. Radargrammetry. McGraw-Hill, New York, 1960, 330 pp.
7. Lewis, A. J. Evaluation of Multiple Polarized Radar Imagery for the Detection of Selected Cultural Features. NASA, Tech. Letter 130, 1968, 28 pp.
8. MacDonald, H. C. Geologic Evaluation of Radar Imagery From Eastern Panama and Northwestern Colombia. Modern Geology, Vol. 1, 1969, pp. 1-63.

9. MacDonald, H. C., Brennan, P. A., and Dellwig, L. F. Geologic Evaluation by Radar of NASA Sedimentary Test Site. Geoscience Electronics, IEEE Trans., GE-5, No. 3, 1967, pp. 72-78.
10. MacDonald, H. C., Kirk, J. N., Dellwig, L. F., and Lewis, A. J. The Influence of Radar Look-Direction on the Detection of Selected Geological Features. Proc., Sixth Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, 1970, pp. 637-650.
11. MacDonald, H. C., and Waite, W. P. Optimum Radar Depression Angles for Geological Analysis. Modern Geology, Vol. 2, 1971, pp. 179-193.
12. MacDonald, H. C., and Waite, W. P. Soil Moisture Detection With Imaging Radar. Water Resources Res. Jour., Vol. 7, No. 1, 1971, pp. 100-109.
13. McAnerney, J. M. Terrain Interpretation From Radar Imagery. Proc., Fourth Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, 1966, pp. 731-750.
14. McCoy, R. M. An Evaluation of Radar Imagery as a Tool for Drainage Basin Analysis. Center for Research, Inc., Univ. of Kansas, Lawrence, Tech. Rept. 61-31, 1967, 101 pp.
15. Morain, S. Field Studies on Vegetation at Horsefly Mountain, Oregon, and Its Relation to Radar Imagery. Center for Research, Inc., Univ. of Kansas, Lawrence, Tech. Rept. 61-22, 1967, 19 pp.
16. Rosenfield, G. H. Stereo Radar Techniques. Photogrammetric Eng., Vol. 34, 1968, pp. 586-594.
17. Wing, R. S. Structural Analysis From Radar Imagery, Eastern Panamanian Isthmus. Modern Geology, Vol. 2, 1971, pp. 1-21, 75-127.
18. Wing, R. S., Overbey, W. K., and Dellwig, L. F. Lineament Analysis, Burning Springs Area, West Virginia—An Aid in the Definition of Appalachian Plateau Thrusts. Geological Soc. of America Bull., Vol. 81, 1970, pp. 3437-3444.

AIRBORNE INFRARED IMAGERY AND ITS LIMITATIONS IN CIVIL ENGINEERING PRACTICE

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•THE RANGE of airborne infrared imaging technology has been greatly expanded in the past decade to include an ever diversifying number of uses. Literature regarding applications abounds, but few authors have addressed the problem of the limitations of the technique.

This paper discusses specific limitations of the infrared imaging technique. Of prime interest is what infrared cannot do for the civil engineer under present state-of-the-art technology. The discussion is divided into the two general categories of geological and hydrological limitations and is based on the experience derived from operational airborne infrared imaging surveys performed since 1963. Comments are limited to information derivable by interpretation from film or positive contact prints of infrared imagery. Generalizations made are meant not to be sweeping statements but to apply only to the specific environments sampled on data collection flights.

GEOLOGICAL LIMITATIONS

As a result of test-flying the various models of RECONOFAX, the line scan infrared imaging systems manufactured by HRB-Singer, Inc., at State College, Pennsylvania, during the past 20 years, this central Pennsylvania region has become one of the most imaged areas in the world in terms of hours of repeated coverage. The area has been flown at all times of the year, both at day and at night, at many different altitudes, and with many different detectors. In addition to this locality, a variety of other geological terranes have come under investigation in the course of contractual projects, primarily in the eastern United States and Canada. Several of these localities will be cited in this paper along with the State College, Pennsylvania, region as examples for the limitations discussed.

State College, Pennsylvania, lies in the Nittany Valley, a predominantly limestone valley surrounded by sandstone ridges with shale slopes. It is a humid region and possesses a soil regolith with a deciduous vegetative cover. The valley is extensively farmed and contains the major population centers of the region; the ridges are wooded. Figure 1 shows a high-altitude daytime infrared image that illustrates this typical ridge and valley topography.

Lithologic Differentiation

No lithologic differentiation has been positively demonstrated on infrared imagery in the State College region. Although in an early paper Lattman (8) indicates that the tonal changes seen on Nittany Mountain are coincident with the contact between a sandstone and a shale, he recognizes that this effect is primarily due to difference in slope and in vegetative cover.

A comparison of imagery and geologic map (Fig. 2) illustrates these interrelations. Figure 3 shows a parallel pass stereo image of synclinal Nittany Mountain. The tonal change follows the ridge crest and not the actual mapped zone of contact in many places. Similar slope-related changes occur in an anticlinal mountain (Fig. 4) where the same sandstone forming the crest of Nittany Mountain here occupies the slope. Although the slope is now sandstone instead of shale, the same warm tone prevails.

Soils differentiation on infrared imagery has not been successful in the Nittany Valley. The masking effect of farmland field patterns and vegetative cover is usually complete.

Figure 1. High-altitude thermal image of typical ridge and valley topography near State College, Pennsylvania, May 5, 1961, 10,000 ft m.s.l., 9:30 a.m., InSb detector.

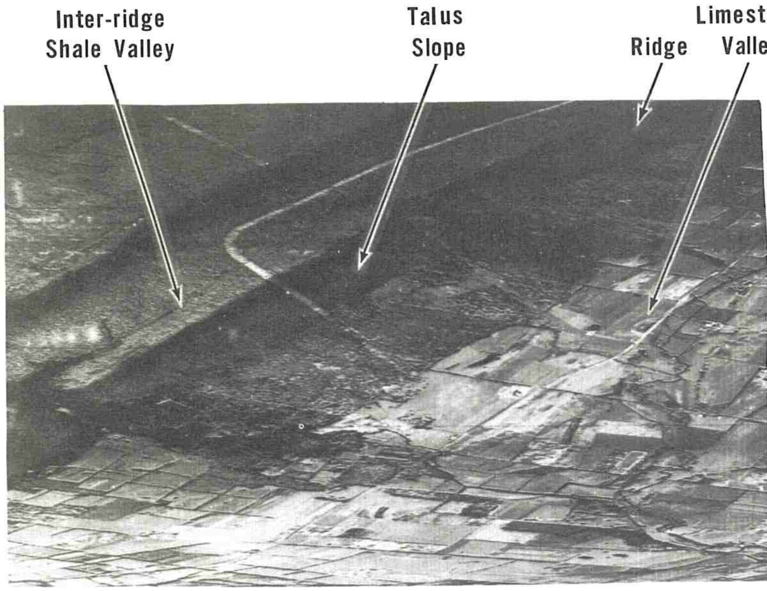


Figure 2. Comparison of thermal image and geological map of Nittany Mountain, October 21, 1959, 5,000 ft m.s.l., 9:30 p.m., InSb detector (O_r = Reedsville shale, and O_o = Oswego sandstone).

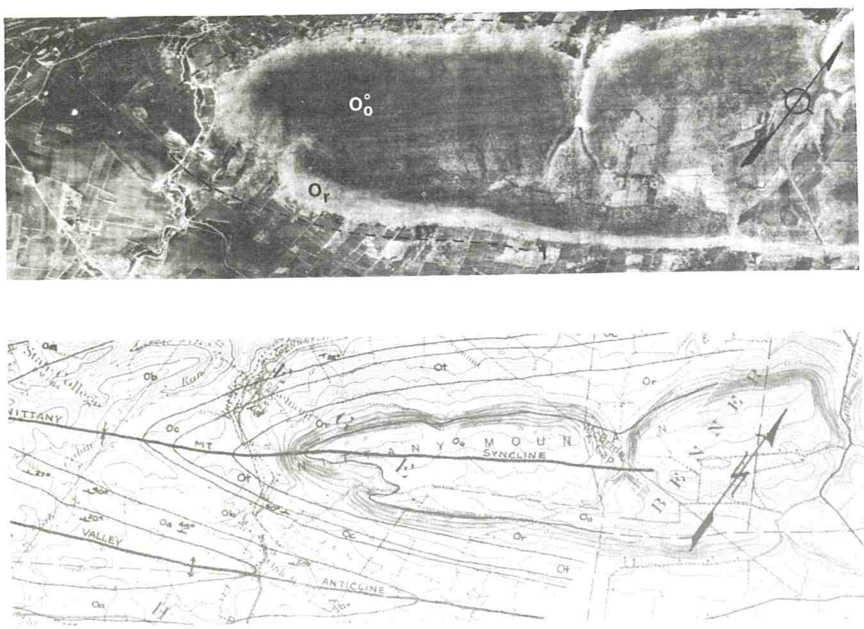


Figure 3. Stereo imagery of Nittany Mountain, October 21, 1959, 9:30 p.m., 5,000 ft m.s.l., InSb detector.

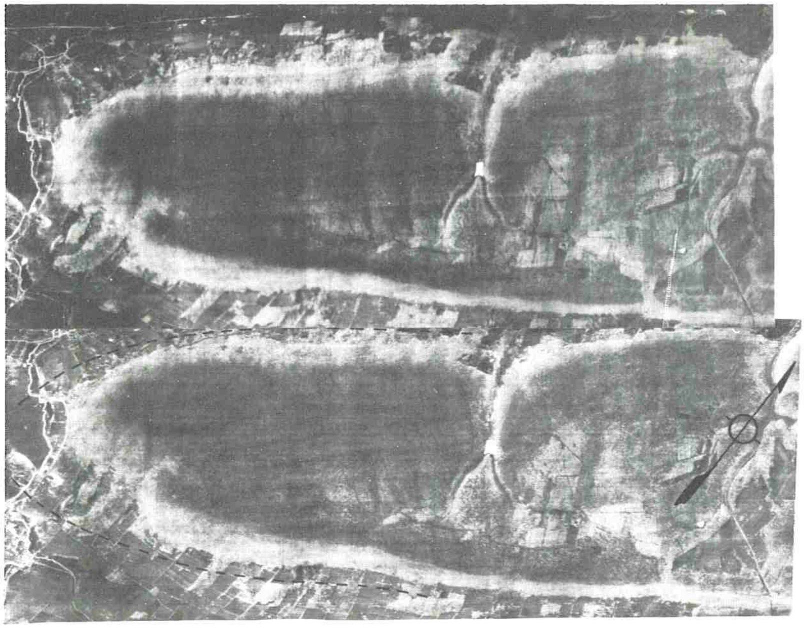
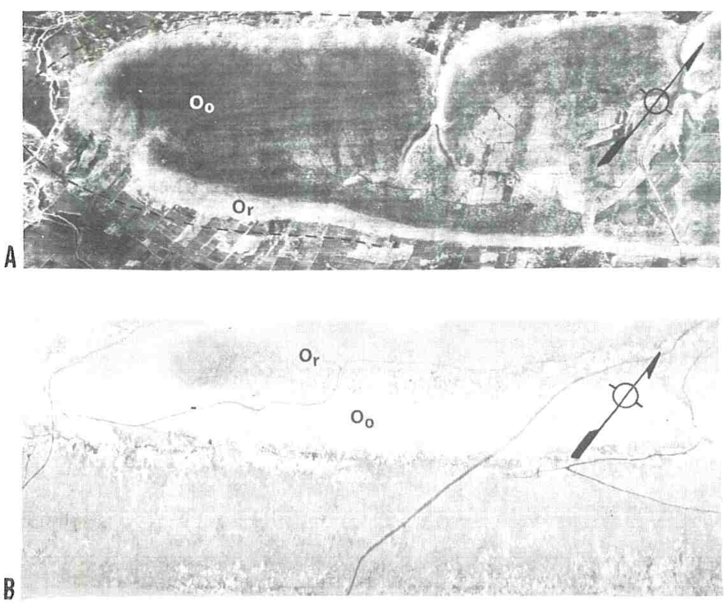


Figure 4. Comparison of thermal imagery of a synclinal versus anticlinal mountain: (a) October 21, 1959, 5,000 ft m.s.l., 9:30 p.m., InSb detector; and (b) January 23, 1967, 3,800 ft m.s.l., 6:17 p.m., InSb detector (O_r = Reedsville shale and O_o = Oswego sandstone).



Humidity and attendant vegetation seem to be critical factors in determining capability for lithologic differentiation. Although Rowan et al. (11) were able to differentiate limestone from dolomite in Oklahoma, no such success has been achieved in the Nittany Valley or at other locations in the eastern United States. It has been by experience that distinct marker beds appear on infrared imagery only when they are also visible on aerial photography either because they are in outcrop or because they are marked by aligned vegetation or exhibit topographic expression.

Void Detection

Evidence of natural caves has not been evident on infrared imagery of the limestone valleys although several known caves were overflown. Extensive use of imagery in searching for buried mine portals, tunnels, and the mines themselves in the bituminous coal fields of western Pennsylvania have all yielded negative results (2).

The use of infrared imagery to find solution cavities beneath the Anchor Reservoir in Wyoming, through which water was being lost, was unsuccessful as a direct method (12). The study was performed while the reservoir was drained, and no surface manifestations of underlying voids were detectable.

In the search for sinkholes, infrared imaging has not proved to be significantly better than aerial photography for detection and positive identification. Suspected sinkholes located in infrared imagery, in most cases, must be checked on stereophotography for positive identification.

Gas Leaks

The use of infrared imagery to detect natural gas leaks in buried transmission lines in New York proved successful only because detection was made of affected vegetation and not of the gas itself (3). Gases, having very low emissivities, are nearly transparent to the infrared detector. Detection, if any, is usually of particulate matter.

Mineral and Petroleum Exploration

Direct imaging of subtle thermal anomalies associated with near-surface oxidizing metallic ore deposits has not been demonstrated successfully in humid climates. Attempts at correlation of near-surface termperature patterns caused by internal heat flow with the disposition of subsurface structures that have heat conductivities different from their immediate environment were unsuccessful in desert climates (10). Friedman (4) has shown that the infrared scanner depicts surface emission directly and heat mass transfer from depths only indirectly and at a threshold level 50 to 100 times the normal conductive heat flow of the earth.

Thermal inertia and solar reflection in minerals are properties claimed to be detectable (5) by an infrared imaging system providing the mineral deposit is exposed at the surface, the outcrop is large enough to be resolvable, and a contrast exists between these properties in the mineral and its surroundings. This may be possible in arid and semi-arid terranes but has not been realized in the more humid climates.

Oxidation of pyrite in strip mines in southeastern Ohio has produced temperature anomalies ranging from 3 to 8 C at a depth of 2 ft (1). Radiant flux calculations theoretically indicate that these areas are mappable with an infrared scanner under favorable conditions. In practice, however, no success has yet been conclusively demonstrated by using infrared imagery. The report in question (1) derived results from interpretation of infrared imagery flown during daylight. The effect of sunlight on a strip mine surface is sufficient to mask any anomaly resulting from an oxidizing mineral.

Subsurface Mine and Coal-Seam Fires

Deep fires in coal seams where overburden of more than 50 ft is present have not been successfully mapped in Pennsylvania (6). Shallow seam and outcrop burning are, however, readily detectable (14). An extensive survey of the burning coal refuse piles in the anthracite region of Pennsylvania (7) has revealed a number of outcrop mine fires. In all instances, however, burning could not be traced much beyond the outcrop.

Experience has shown that useful imagery of subsurface fires is not obtainable at altitudes greater than 10,000 ft above terrain or where ground resolutions exceed 10 ft square. Useful imagery is also not obtainable when direct sunlight is shining on the bank. Data collection flights are scheduled for night, twilight, or cloudy days.

HYDROLOGICAL LIMITATIONS

In this category, surface water and groundwater are included, and the main limitations are in water quality determinations and in shallow aquifer exploration.

Water Quality

Although an excellent technique for detection of thermal differences in water bodies, infrared imaging provides little direct data on water quality. Effluents may be described in terms of radiation temperature differences that in many cases are emissivity related. In acid mine-water discharges, temperature of discharging waters is sometimes relatable to water quality. If this is the case, then the availability of quantitative data such as calibrated imagery or supplemental radiometer data can prove effective in the comparison of temperatures of natural springs in acid-free terrain with those of discharging mine waters. If there are no quantitative data, the relative tones depicted on infrared imagery are usually too subtle to differentiate acid from non-acid waters.

Shallow Aquifer Detection

The search for groundwater in the presence of shallow aquifers has been investigated by O'Brien (9) in New York State. Definite temperature anomalies exist below the surface but were not visually present on infrared imagery of the surface.

An early use of infrared imagery (13) in the search for a buried glacial channel suspected of transporting water from the St. Lawrence River to the Ottawa River near Vaudreuil, Quebec, provided negative results although some evidence for possible emergent waters was observable in the Ottawa River itself.

PRACTICAL APPLICATION

As an illustration of the practical use of infrared imagery and its limitations, I cite 2 recent projects, both in the Appalachians, completed for engineering concerns involving airborne infrared imagery: One was a survey of a proposed highway route, and the other was a survey for a reservoir site.

For the highway site, the primary feature sought was potential landslide areas. These were identified by the delineation of seepage areas as they appeared on the imagery, and cross faults were identified by displacements in these seepage zones. No lithologic differentiation was made. The detection of seepage zones in this case was enhanced by the data collection survey being flown during the late fall, at night, and with air temperature well below groundwater temperature. Under these conditions, groundwater seepage appears as white (warm) tones against a dark background, which makes optimum the interpretability of the image.

For the reservoir site, the same environmental criteria were used to determine the time and the date for data collection. Here springs, sinks, faults, and landslide areas all were of interest. In this area, underlain partially by metamorphic and sedimentary rock, again no lithologic differentiation was possible. Optimum detection of springs and seepage zones was realized together with some success in tracing a fault zone.

In both areas the infrared excelled in depicting surface water and moisture-related linear geologic features. Soils and lithologic differentiation were not possible.

COMPUTER PROCESSING

The trend toward taping airborne infrared signals in order to retain their full range shows some promise in attacking those areas lying at or close to threshold levels of signal/noise. Digital processing of calibrated signals permits great flexibility in

Figure 5. Computer-generated gray scale slices of a coal refuse pile fire in Pennsylvania (slicing is illustrated at discrete voltage levels that can be converted to radiation temperatures).

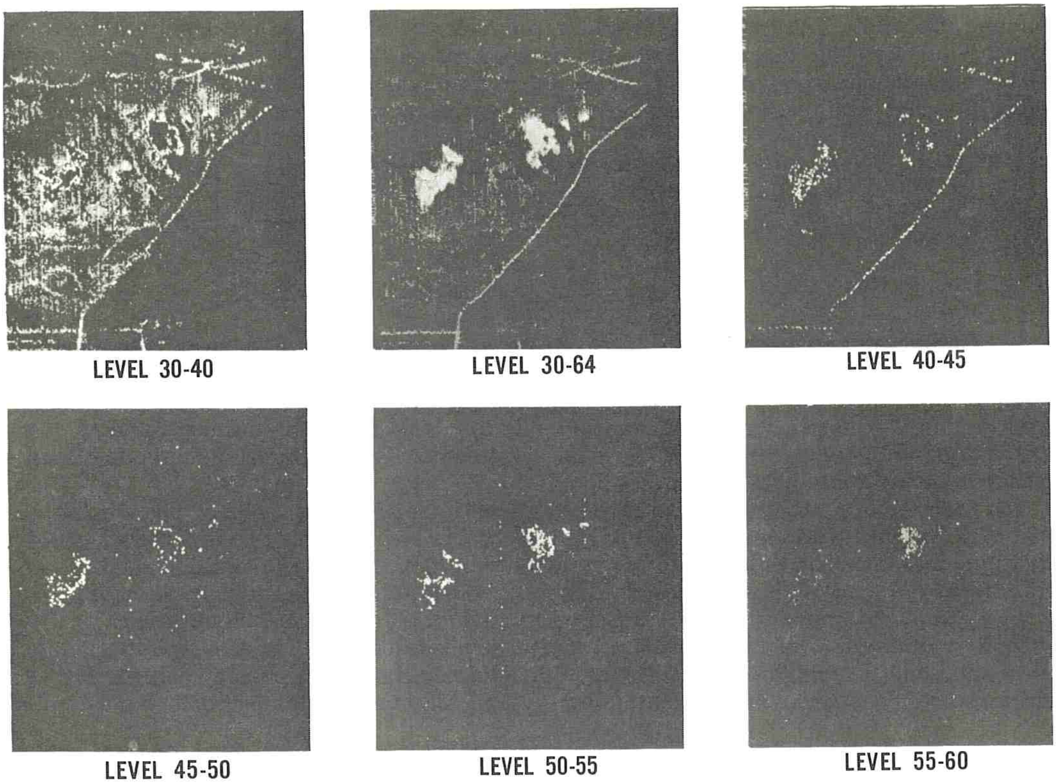
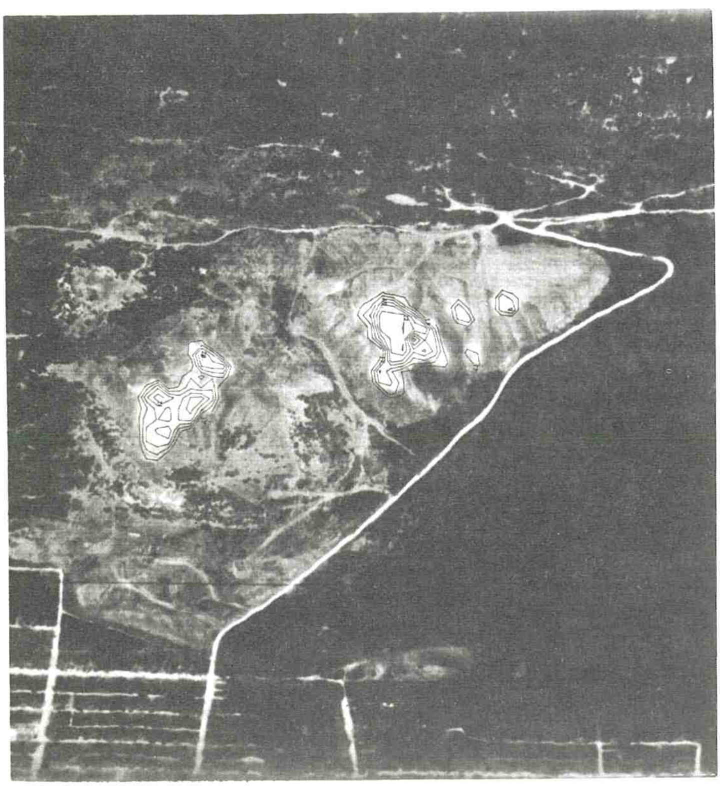


Figure 6. Computer-generated thermal contour lines overlaid on a thermal image of a burning coal refuse bank in Pennsylvania.



handling the data. The individual investigator may experiment on different voltage levels, equivalent to calibrated radiation temperatures, and apply computer programs to glean data heretofore beyond the retrieval level of the human eye. As an example, detail in a coal refuse pile fire can be reconstructed by gray level slicing techniques, and a contour map can be automatically produced by the computer (Figs. 5 and 6). This detail is usually obscured on infrared imagery by the excessive heat of the fire area exceeding the dynamic printing range of the film. Work is currently being done on extending these techniques into some of the areas discussed as limitations in this paper.

SUMMARY

The information available from infrared imagery is limited for certain geological and hydrological applications. At best, it is a marginal technique in the following areas of interest to the civil engineer and geologist: lithologic differentiation including soils in humid climates, subsurface void detection, gas detection, mineral and petroleum exploration, deep mine fire detection, water quality investigations, and shallow aquifer exploration in humid climates.

The technique is, in practice, limited to detection of surface thermal phenomena or subsurface manifestations that are carried to the surface and are present at threshold levels greater than the noise level of the system or interference levels of masking features or both. For those areas of marginal usage discussed, infrared imagery may be useful in conjunction with, but never without, a good aerial photograph.

Some promise is noted, however, in digital processing of infrared signals to glean data from near threshold levels. Computerized analysis programs may be able to retrieve data currently beyond the retrieval level of the human interpreter.

REFERENCES

1. Ahmad, M. U., and Ghosh, B. A. Temperature Survey of Coal Mines Producing Acid Water. Proc., Seventh Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, May 1971.
2. Fisher, W. Detection and Location of Concealed Abandoned Underground Coal Mines and Associated Water Movement Avenues by Geophysical and Geochemical Techniques. HRB-Singer, Inc., Rept. 4411-F, Aug. 1971.
3. Fisher, W., Knuth, W. M., and Stingelin, R. W. Aerial Infrared Surfey of the Negro Mountain, Maryland, Gas Production Field, the Greenwood, New York, Gas Storage Field and the Wellsville, New York, to Greenwood, New York, Gas Transmission Lines. HRB-Singer, Inc., Rept. 4149-F, March 1968.
4. Friedman, J. D. The Airborne Infrared Scanner as a Geophysical Research Tool. Optical Spectra, Vol. 4, Issue 6, June 1970, pp. 35-44.
5. Greene, G. W. Mineral Exploration Using an Airborne Infrared Imaging System. Proc. Seventh Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, May 1971.
6. Knuth, W. M. Airborne Infrared Imaging Techniques in Coal Mine Fire Location: Connellsville, Pennsylvania. HRB-Singer, Inc., Rept. 4335.11-R-3, Nov. 1969.
7. Knuth, W. M. Compendium of Burning Coal Refuse Banks... Pennsylvania, Vol. 1, Anthracite Region. HRB-Singer, Inc., Dec. 1971.
8. Lattman, L. H. Geologic Interpretation of Airborne Infrared Imagery. Photogrammetric Engineering, Vol. 29, No. 1, Jan. 1963, pp. 83-87.
9. O'Brien, P. J. Aquifer Transmissivity Distribution as Reflected by Overlying Soil Temperature Patterns. Department of Geology and Geophysics, Pennsylvania State Univ., University Park, PhD thesis, Dec. 1970.
10. Poley, J. P., et al. Exploration for (Shallow) Geological Structures With Thermal Infrared Imagery Technique in Some Desert Areas of Oman. Proc. Seventh Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, May 1971.
11. Rowan, L. C., et al. Thermal Infrared Investigations, Arbuckle Mountains, Oklahoma. Geological Soc. of America Bull., Vol. 81, Dec. 1970, pp. 3549-3562.

12. Stingelin, R. W. Anchor Reservoir, Wyoming; Preliminary Interpretation Report. HRB-Singer, Inc., prel. rept., Aug. 1968.
13. Stingelin, R. W., and Ory, T. R. Airborne Infrared Survey Experiments in Canada. HRB-Singer, Inc., Rept. 941-F, Feb. 1966.
14. Stingelin, R. W., and Knuth, W. M. Airborne and Ground Geologic Analysis of Subsurface Burning at Coal Hill, Snow Shoe, Pennsylvania. HRB-Singer, Inc., Rept. 450101-R-1, May 1971.

MULTISPECTRAL SCANNING SYSTEMS: THEIR FEATURES AND LIMITATIONS

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Multispectral sensing is a space-age development made possible through a number of technological developments, improved optical-mechanical technology, advances in solid-state detectors and electronics, advances in data handling and recording techniques, and widespread use of computers. Multispectral sensing has the potential for surveying large areas in a short time and for classifying features automatically on the basis of their spectral characteristics. That some classification based on spectral information is feasible is not questioned. Rather the question is, How fine can one carry out the classification process with a given level of complexity? That is, What are its limitations?

•THE INFORMATION in the radiation from a scene is derived from spatial distribution, spectral distribution, temporal variations, state of polarization, and variation of these parameters with the angle of observation.

By their very nature, image-forming sensors produce graphic representations of the spatial distribution of the radiation from the scene. Interpretation of such imagery relies heavily on shape recognition of key elements within the scene and on some analysis of tone. And, to be sure, some sensors take advantage of the spectral distribution of the target and background radiation in order to increase the contrast between objects and backgrounds by selecting optimum film-filter combinations (spectrozonal photography). The relative tone of objects within the scene of spectrozonal photography has proved to have limited usefulness, however, in the differentiation of types of forest plantations, classification of soil, classification of land use, early detection of some crop diseases, and identification of agricultural crops (1, 2, 3, 4, 5, 6, 7). In all instances, a rather limited specific wavelength region is used where gross spectral differences occur among the objects or effects being sought and their backgrounds.

Although quantitative evaluation of tonal variations in single-band imagery has many limitations (1, 2, 3, 4, 5, 6), it does offer a limited means for the automatic interpretation of some types of imagery. An example is in agriculture, where seasonal planting and growth cause fields to undergo dramatic changes as a function of time (7).

In many remote-sensing applications with extensive coverage, identification through shape from high-resolution imagery requires too large a data bulk. Consider satellite photography of the United States with 2-ft ground resolution, for example. It would take roughly 3,000 lb of film to produce this coverage, and it would take a 10-MHz telemetry link 120 days to transmit this information to earth. If some identification can be done on the basis of spectral information, it may be possible to reduce the sensor resolution requirements. In agricultural sensing for survey purposes, one wishes only to know what a farmer has in a field. Resolution of the crop structure itself is not feasible for large-area coverage, but it may be possible to distinguish the crop with a low-resolution system on the basis of its spectral signature. If such a detection is possible, a ground resolution of 200 ft might be adequate—in which case the resulting imagery of the United States could be recorded on $\frac{1}{3}$ lb of film and the telemetry time reduced to about 17 min.

Although spectrochemical analysis is widely used in the laboratory for identifying materials and spectrophotometric techniques are used for process control and sorting, these techniques have not received widespread use in field applications such as identi-

fication of terrain features or conditions. The reluctance to use them is largely attributable to the lack of controlled conditions associated with field operations; e.g., meteorological conditions affect the radiation received by a remote sensor, and nature produces variance within a given class of material. Notwithstanding these limitations, spectral reflectance and emittance observations made largely by earth resource scientists indicate that moisture stress in plants, vigor of vegetation, land use classification, mineral identification, and crop and soil identification are possible under limited conditions of observation (8, 9, 10, 11, 12, 13). These measurements are not confined to the photographic region, and most are being made by nonimaging sensors.

MULTISPECTRAL SCANNER

Modern technology makes it possible to build imaging sensors to operate in almost any region of the electromagnetic spectrum. Scene elements or features that are not contrasted in one region of the spectrum can often be contrasted in another region. As a result, many users of remote sensing have resorted to using multiple sensors in order to obtain the information they are seeking. This approach is a mixed blessing because the interpreter of this multichannel imagery must now intercompare corresponding scene points in the various images in order to obtain the desired information. The multichannel imagery approach places an added burden on the interpreter, who is already the limiting link in the information system's throughput. The multispectral scanner offers an approach that can automate the process of analyzing the spectral radiation characteristics of each element in the scene and of making judgments based on this information.

There are a number of ways to implement a multispectral scanner. The technique preferred for many band operations is that which combines an airborne line scanner with a multichannel spectrometer (14). In an airborne scanner the ground is scanned in a systematic manner, as shown in Figure 1, and the measured radiation is graphically displayed or recorded. The detector is used as the field stop, and a filter is placed in the radiation path to limit the wavelength of operation to the particular wavelength region of interest (usually 4.5 to 5.5 μm or 8 to 14 μm). Instead of rejecting this "unwanted" radiation with an optical filter, a multispectral scanner uses the entrance slit of a multichannel spectrometer as the field stop (Fig. 2), and all of the radiation passes through the spectrometer. In such a system, each detector of the spectrometer observes the same resolution element of the scene but in a different wavelength region.

The output signal from each detector element is a video signal corresponding to the scene brightness in the particular wavelength region of operation. This video signal can be used to generate an image of the scene in the wavelength region, which is defined by the position of the detector in the spectrometer. The output signals from multiple detectors can be combined to determine the spectral distribution of the radiation from each scene point. This spectral information then can be used selectively to enhance or suppress the brightness of objects or materials in a scene on the basis of their spectral radiance. Thus, the multichannel video data can be fed to a signal processor that is designed to generate a single video signal where intensity, for example, is a function of how closely the spectrum of a scene point corresponds to a spectrum being sought.

Figure 3 shows a schematic of a multispectral scanning system configured as a research tool. In addition to measuring the radiation from the scene, the scanner observes calibration and reference sources. The data from the various channels are registered in both time and space and are recorded on tape for analysis and processing in the laboratory. One of the more sophisticated multispectral systems has been built by Bendix for NASA to be used in support of NASA's earth observation program (15). The scanner operates in 24 spectral bands between 0.32 and 13.5 μm. Figure 4 shows the airborne scanner subsystem, and Figure 5 shows the ground data subsystem used for screening, editing, analyzing, and processing the tape-recorded data.

Figure 1. Line scanner.

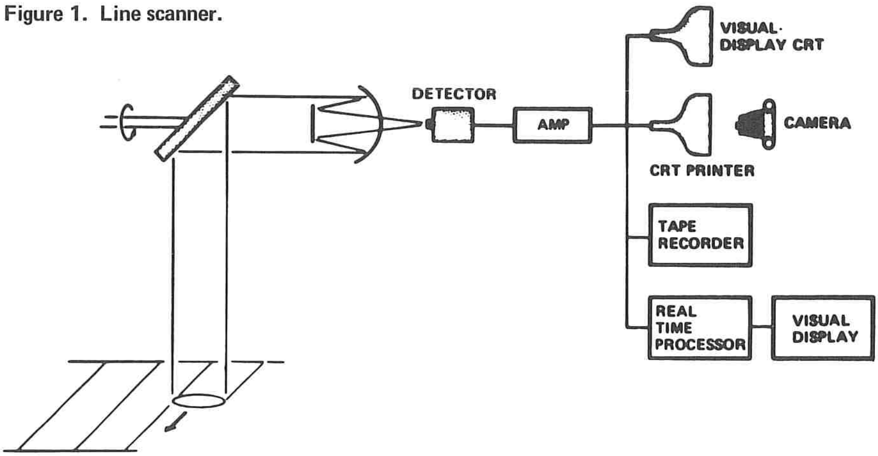


Figure 2. Dispersing multispectral scanner.

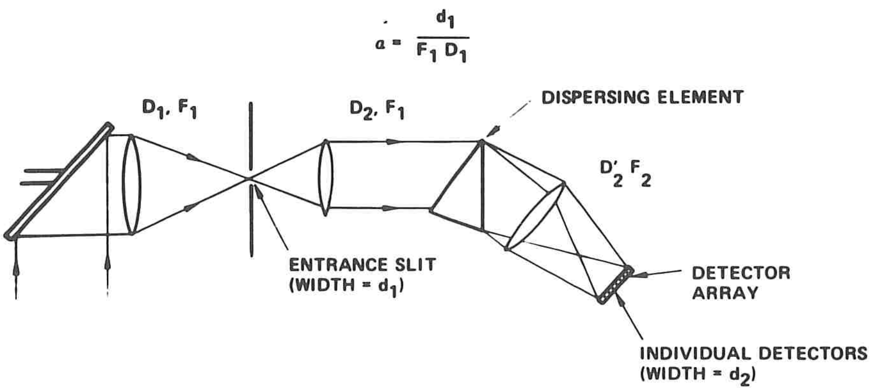
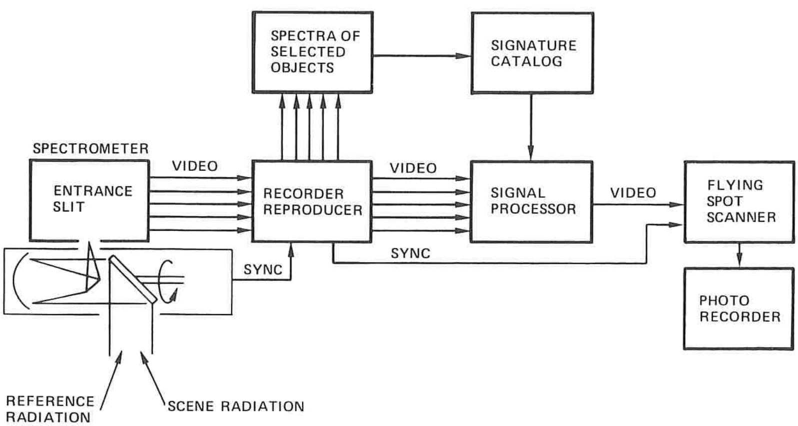


Figure 3. Multispectral scanner and data processor.



EXAMPLES OF MULTISPECTRAL APPLICATIONS

The potential of multispectral scanners for probing the environment around us and for assessing the allocation of natural resources available to us is constrained at present by the relatively limited research into applications of the techniques. Although such research is being conducted by a number of investigators, the applications-oriented research has been limited in scope by the few multispectral scanners and ground data processing stations available. Multispectral scanners are currently being flown by the University of Michigan, the Bendix Corporation, and the NASA Manned Spaceflight Center (MSC). Ground processing stations are currently in use at the Purdue University Laboratory for Applications of Remote Sensing (LARS), the University of Michigan Institute of Science and Technology, the Aerospace Systems Division of the Bendix Corporation, and MSC. A ground station for processing multispectral data from the ERTS satellite was delivered to NASA/Goddard last fall (16). Thus, although the availability of such equipment is still limited, a number of new equipments will be available in the near future.

The major advantages over manual photo interpretation expected from multispectral scanners include relatively rapid assessment of large areas and/or detection and enhancement of relatively subtle spectral variations, among features using statistical analysis techniques. The processed data output can be presented to the user in a number of ways, of which some representative examples will be shown.

The first example is a computer-generated classification map on which printer symbols are used as the target identifier (17). The data were gathered with the University of Michigan 18-channel multispectral system in May 1967. Aerial photography was also collected for comparison with the processed scanner data. The purpose of the program was the automatic mapping of soil surface conditions. The test area was in Morgan County, Indiana, near Bloomington. The left half of Figure 6 shows an aerial photograph of a portion of the test area. The multispectral scanner data were processed by the LARS data processing facility to yield the computer printout shown on the right half of the figure. The computer was programmed to distinguish bare soil from all other targets and to print only target cells in the data recognized as soil. In addition, the computer was programmed to recognize dark and light patterns in the soils. These categories of soil patterns were printed as dark, medium, and light soils. The process could be continued until the number of levels desired by the user was obtained or until the noise limitations inherent in the data were reached, whichever occurred first.

Processing of multispectral scanner data is not limited to the digital computer approach. Analog processing techniques may also be used to yield similar results, and analog-digital hybrid techniques may be used. An example of processed multispectral scanner data using analog techniques is shown in Figure 7; the left half of the figure shows an aerial photograph of part of the test area, and the right half shows processed multispectral scanner data (18). The data were collected on March 24, 1969, near Lake Charles, Louisiana; a Bendix 9-channel multispectral scanner was used. The program was sponsored by the Geographic Science Division, U.S. Army Topographic Laboratory, Ft. Belvoir, Virginia. The purpose of the program was to develop techniques for automatic detection and classification of construction materials. The output of the Bendix data processing facility was in the form of a color-coded image consisting of 3 target classes: water, colored blue; sand, colored brown; and vegetation, colored green. The reproduction here is a black-and-white copy of the original color image. The classification was performed by the use of a hybrid technique: The determination of the method of processing to be used was performed in a digital computer by using samples of the target categories from the scanner data for "training," while the actual data processing was performed in an analog data processing facility and was based on the results of the computer analysis.

The 2 types of processed data presented above are called "decision imagery" because the processing system made a decision as to the most likely target material present in each scanner resolution cell and produced only the results of that decision in the form of a target identification. In this type of presentation, the target is presented as a

Figure 4. NASA 24-channel airborne multispectral scanning system.

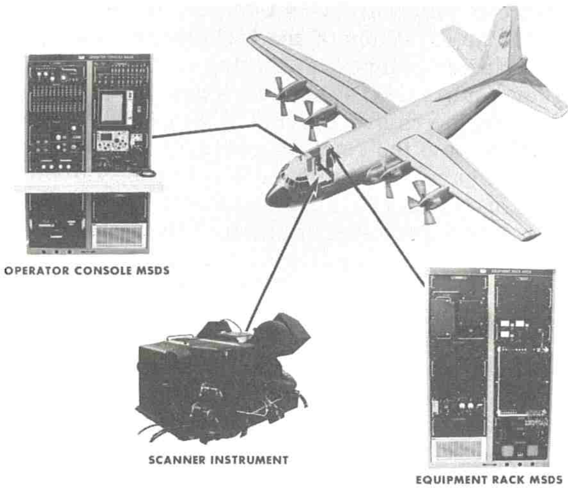


Figure 5. 24-channel scanner subsystem for data analysis.

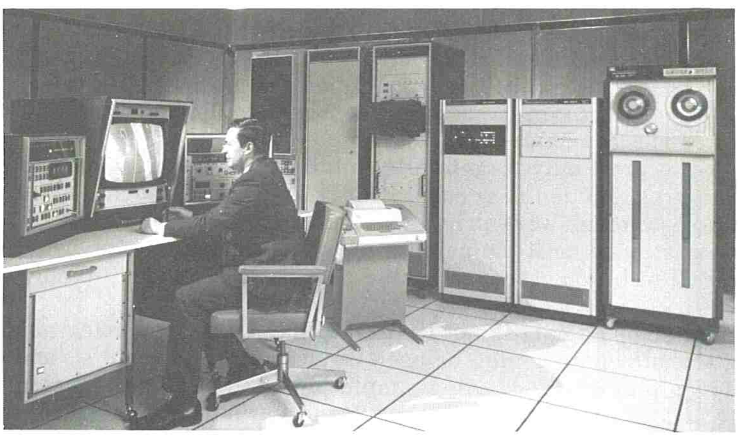
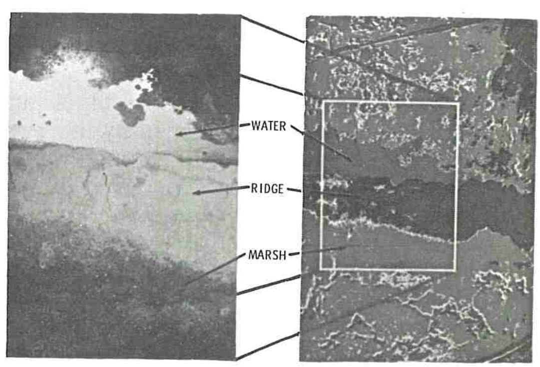


Figure 6. Aerial photograph and computer printout of dark, medium, and light soils.

Figure 7. False color classification of multispectral data from computer analysis.



symbol or a color with no tonal variations or gray scale. The processed results can also be presented as "enhanced" imagery, where tonal variations represent the probability that the imagery contains the desired target material. The imagery can be presented as black and white for a single target type, or it can be presented as different colors for multiple targets and the color saturation can indicate specific target category probabilities. Color enhancement can also be used to accentuate subtle variations in the imagery for easier interpretation by the investigator. Examples of enhanced imagery are not shown in the text because of the limitation of black-and-white offset reproduction.

Digital processing techniques are not limited to computer printout presentations. Digital processing systems can be built, and do exist, that drive a color film recorder with presentations similar to that of analog systems. The principal advantages of digital systems that use general-purpose computers are programming flexibility and, if the data are available in the form of computer-compatible magnetic tapes, wide availability of existing large-scale computer facilities. The principal advantages of analog processing systems are real-time, high-speed processing and lower facility cost. The mathematical basis for performing the processing and the statistical analysis theory on which the processing is based are similar in both cases.

Although the advantages of automatically processing data from large areas of terrain have been cited and the system does exist as a potential, most research conducted to date has consisted of feasibility demonstrations using data from small areas. Use of the techniques has been confined to small-scale feasibility demonstrations both because of the paucity of suitable equipment and because of the limitations in reducing the techniques to operational procedures. These limitations can be discussed in terms of the parameters that affect classification accuracy.

PARAMETERS AFFECTING CLASSIFICATION ACCURACY

In the examples of processed multispectral imagery previously presented, a number of common factors exist. In both the color imagery and the computer line-printer imagery, the observables of interest could be easily sorted into 3 distinct classes: vegetation, water, and soil (sand in the color imagery). In the Purdue line-printer imagery, the additional classification of soil tone was performed within the target class soil. In both examples, the variations between target classes were large compared to variations within the individual classes themselves; consequently, the classification could be performed with a high degree of accuracy and a low false alarm rate. Regardless of the application or use to which the data are being put, 2 conditions must exist for automatic classification of target categories:

1. The target classes must be separable in the data as seen by the collection instrument, and
2. The variations within the target classes must be small relative to the variations among target classes.

Before describing environmental, instrumentation, and background effects that affect these 2 conditions, let us illustrate the 2 conditions with an example. The color imagery shown previously was generated from data collected with the Bendix 9-channel multispectral scanner. For computer analysis, "training samples" were selected from the desired target categories in the imagery to determine the methodology to be used in the analog data processing. For the example, only the first 8 channels were used in the processing. Figure 8 shows the means and the standard deviations for the 3 target categories arranged as 8-channel spectra of the targets. To increase the ease of separation of the 3 target categories, a coordinate rotation of the 8-channel data was performed that concentrated the characteristics for separating the target categories into a limited number of synthesized channels (18). It is beyond the intent of this paper to go into the details of automatic data processing; therefore, the details of the coordinate rotation will not be discussed. Figure 9 shows the 3 target categories in the rotated coordinate system, again with the means and standard deviations of the target categories. For the first 2 channels, the variations within target classes are

small compared to the variations between target classes, and the target classes are separable. This meets the 2 conditions specified for classification. (The 2 conditions were not met in the raw data; an important function of the data processing is to manipulate the data so that the 2 conditions are satisfied.)

Figure 10 shows the data points of the training set corresponding to the first 2 channels plotted against each other. The data points fall into "clusters." The color imagery shown was generated by electronically generating classification windows and assigning a color to each of the windows. The white areas in the imagery are data points that fell into none of the windows. Some of the nonwindowed data points are targets that did not fall into the 3 categories of sand, marsh, and water (such as roads and artifacts), while other data points were targets of the desired categories whose radiation characteristics did not, in fact, fall within the expected window. For discussion purposes, let us assume that the imagery contains only the 3 target categories and that all points that fall out of the windows are misclassifications. What are the factors that cause misclassification of the data?

Ideally, it would be desirable for target categories to fall in small, closely knit groups with different target categories widely separated from each other. In actuality, this does not occur for a number of reasons. There are 4 general sources of variance in the data:

1. Poor correlation between the observables and the desired target categories,
2. Variations within the target categories,
3 Environmental effects, and
4. Instrumentation effects.

The first source, poor correlation between the observables and the desired target categories, is the only source that determines the inherent ability to distinguish between target categories and that can be regarded as related to the separation among the means of the target clusters. An inherently distinguishable set of targets can be degraded by other factors, in effect, by increasing the size of the target clusters through other sources of variance until the clusters are overlapped beyond distinguishing. An important first step in a feasibility investigation should be to determine with laboratory measurements, field measurements, or other means that the targets in question have sufficient signature or spectral differences for classification. It must also be borne in mind that multispectral scanners detect only surface phenomena. If detection of phenomena beneath the surface visible to the scanner is desired, there must be a correlation between the subsurface phenomena and the surface effects, and the correlation must be established. The methodology of data processing also contributes to the ability to distinguish among targets. In the example cited, a transformation or coordinate rotation of the data was performed to increase the separability of the target classes. After rotation, the targets were sufficiently separable to permit classification with simple rectangular windows. The major emphases in signature-processing research and development are currently placed on development of transformation techniques to ensure the maximum separability of target categories and on methods of storing target distributions (the window approach is a simplistic target-distribution storage method) to map adequately the boundaries between target categories.

If it is assumed that the observable targets of interest are inherently capable of classification and that the observables are related in some way to the desired phenomenology, the remaining sources of error cited as causes of misclassification contribute to increasing the size of the target clusters relative to the spacing between the clusters; hence, the contribution to misclassification is no less than the area of statistical overlap between the 2 or more target clusters. Each of these sources of error will be discussed in turn.

Variations within target categories can be caused by intrinsic variations in the targets themselves, such as the soil tonal variations in the computer printout examples, or by environmental or instrumentational factors, which will be discussed separately. Intrinsic target variations can be handled in several ways. Each variation in the target category can be treated as a separate target. This was done, in effect, in the computer printout example. An alternative method of treatment is to derive a target

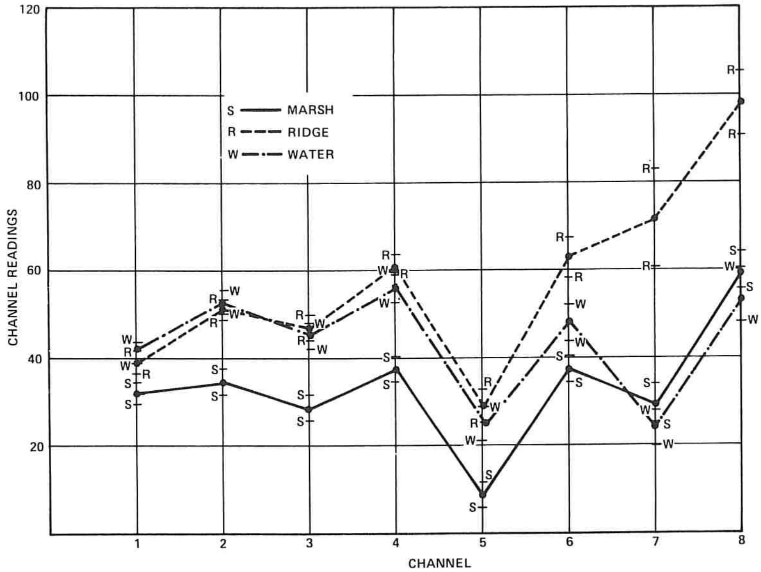


Figure 8. Reflectance spectrum of 3 terrain types.

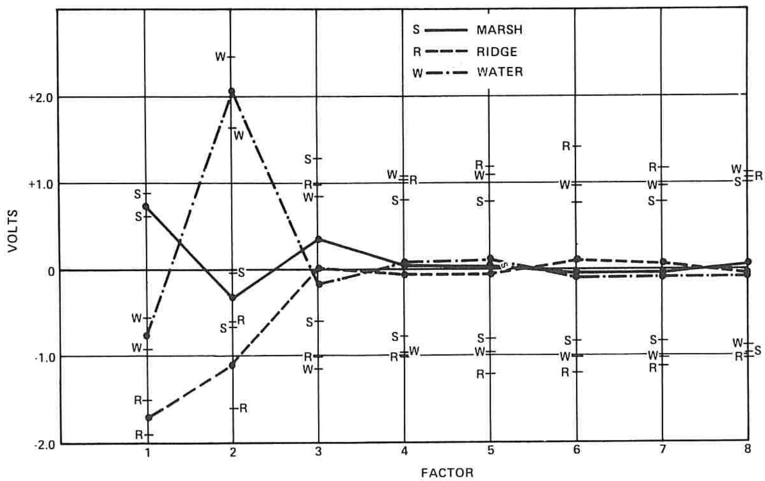


Figure 9. Factor score distribution of 3 terrain types.

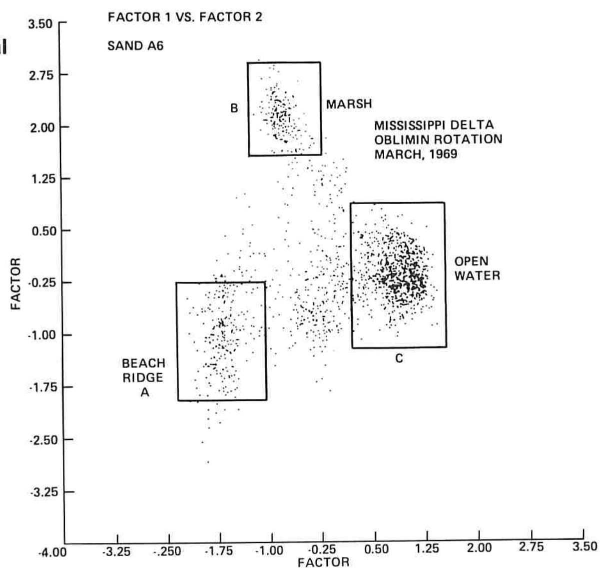


Figure 10. Scatter diagram of multispectral data.

distribution description that follows the apparent boundary of the target cluster. Both approaches are being used in data processing technique development. In either case, it is very important to include a sufficiently large number of target data samples in the training set to ensure that all likely variations of the target signature are included. If this is not done, misclassifications can occur because an allowable variation of the target is not recognized.

Environmental effects as a source of misclassification are 1 of the 2 major limitations of multispectral scanners today. The major factors considered under environmental effects are atmospheric attenuation and scattering, spectral and intensity variations in illumination, signal variations with view angle and sun angle, and surface conditions such as snow, moisture, and wind. Many of these factors can be accommodated provided that an adequate theoretical model of the environmental effect exists and that practical methods of implementing corrections of the raw data can be carried out. Many investigators are already incorporating corrections for view angle, sun angle, and illumination variations as preprocessing steps in manipulating the data (19). The NASA 24-channel scanner includes 2 channels specifically designated to measure atmospheric attenuation between the aircraft and the ground; and, if there is an adequate atmospheric model, the measurements can be used to correct the signals from the remaining channels. In addition, if the target clusters are well separated, the environmental effects can be considered as another source of target variance in the processing.

Nothing can be done about environmental effects such as snow cover because the multispectral scanner observes only surface phenomena.

The second major current limitation of multispectral scanners is the classification errors caused by instrumentation effects. Signal-to-noise deficiencies in a scanner will increase the apparent size of the target cluster by superimposing a Gaussian distribution on an otherwise normal target distribution if the noise is random. If not random, a non-Gaussian distribution will be imposed. Random system calibration errors will have the same effect, and nonrandom errors will distort the distribution in some manner. Calibration errors can occur in the instrument itself, in the data recording and reproduction process, or in the data processing system. It has been mentioned that field measurements should be made to determine the inherent separability of target categories. An important reason for performing these measurements is to determine the amount of random variations tolerable in the multispectral scanner and to separate the target classification and instrumentation problems.

A source of instrumentation error that can also be classed as target variation is interaction of the instantaneous field of view, or resolution cell, of the scanner with the target. In the cluster diagram shown in Figure 10, a number of data points are randomly scattered in the spaces among the windows. If it is assumed that only the 3 target types exist in the imagery, these points can occupy this space for either of 2 reasons. First, more than one target could have been in the resolution cell when the sample was taken. Obviously, if the sample contained half sand and half vegetation, the data point will fall between the 2 target clusters and will be classified as neither. The second possible reason is channel-to-channel misregistration in either the scanner or the tape recorder. If one channel is looking at a different ground patch containing a material different from that in other channels, the target signature will be distorted and misclassified. Misregistration in the instrument can be solved by the use of a spectrometer for spectral channel selection and by the use of a field stop in the collecting optics image plane as the entrance aperture of the spectrometer. Tape recorder misregistration can be solved by the data being recorded digitally. Both approaches are being used in the new second-generation multispectral scanners.

SUMMARY

Multispectral sensing is a space-age development made possible through a number of technological advances, including improved optical-mechanical technology, advances in solid-state detectors and electronics, advances in data handling and recording techniques, and widespread use of computers. Multispectral sensing has the potential for surveying large areas in a short time and classifying features automatically on the basis

of their spectral characteristics. The feasibility of some classification based on spectral information is not questioned. But its limitations need to be known. To what specific extent can one carry out the classification process with a given level of complexity?

Most of the limitations in multispectral sensing arise from a lack of experience in the use of this new sensing technique. Like a child, the technique will have to undergo the time it takes for training, failures, and successes that lead to maturity and fulfillment. Successful applications will come only through experimentation. Many of the limitations are brought about by an underlying philosophy of "let's keep the instrumentation simple or at least minimize its complexity" in order to make the technique attractive. For example, one is certain that the spectral radiance of a scene element is affected by the view angle and solar insolation angle. Even though both of these parameters are known, they are not generally accounted for in the ensuing data processing. In contrast, human perception adapts to these factors by accounting for them automatically. In many instances, a trade-off analysis must be conducted, for minimizing the limitations may involve a price to pay in complexity, dollars, or throughput or all of these. But the potential and the payoff of multispectral sensing warrant the patience to evaluate the technique experimentally in order to determine its limitations for a given application.

REFERENCES

1. Colwell, R. N. Manual of Photographic Interpretation. American Society of Photogrammetry, George Banta Co., Menasha, Wisc., 1960.
2. Colwell, R. N. Some Practical Applications of Multiband Spectral Reconnaissance. American Scientist, Vol. 49, 1961, p. 9.
3. Doverspike, G. E., Flynn, F. M., and Heller, R. C. Microdensitometer Applied to Land Use Classification. Photogrammetric Eng., Vol. 31, 1965, p. 294.
4. Poley, J. Contrast Enhancement in Photogeology by Selective Filtering. Photogrammetric Eng., Vol. 31, 1965, p. 368.
5. Meier, H. K. Uses of Infrared Emulsions for Photogrammetric Purposes. Soc. Phot. Inst. Eng. Jour., Vol. 1, 1962, p. 4.
6. Steiner, D., and Haefner, H. Tone Distortion for Automated Interpretation. Photogrammetric Eng., Vol. 31, 1965, p. 269.
7. Brunnschweiler, D. H. Seasonal Changes of the Agricultural Pattern: A Study in Comparative Airphoto Interpretation. Photogrammetric Eng., Vol. 23, 1957, p. 131.
8. Romanova, M. A. Air Survey of Sand Deposits by Spectral Luminance. Consultants Bureau, New York, 1964.
9. Raspolozhenskii, N. A. An Airborne Spectrometer for the Study of the Spectral Brightness of Landscape Features. Geodesy and Aerophot., Vol. 6, 1964, p. 358.
10. Aronson, J. R., et al. Studies of the Middle- and Far-Infrared Spectra of Mineral Surfaces for Application in Remote Compositional Mapping of the Moon and Planets. Jour. Geophysical Res., Vol. 72, No. 2, Jan. 15, 1967.
11. Myers, V. I., et al. Factors Affecting Light Reflectance of Cotton. Proc. Fourth Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, June 1966, p. 305.
12. Lyon, R. J. P., and Patterson, J. W. Infrared Spectral Signatures: A Field Geological Tool. Proc. Fourth Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, June 1966, p. 215.
13. Adams, J. B., and Felice, A. L. Spectral Reflectance 0.4 to 2.0 Microns of Silicate Rock Powders. Jour. Geophysical Res., Vol. 72, No. 22, Nov. 15, 1967, p. 5705.
14. Lowe, D. S., and Braithewaite, J. G. N. A Spectrum Matching Technique for Enhancing Image Contrast. Applied Optics, Vol. 5, June 1966, p. 893.
15. Zaitzeff, E. M., et al. MSDS: An Experimental 24-Channel Multispectral Scanner System. IEEE Trans., Geoscience Electronics, GE-9, No. 3, July 1971.

16. Johnson, R., and Buiten, R. Design of the ERTS Image Processing System. 8th AIAA Meeting, Washington, D. C., Oct. 25-28, 1971.
17. Kristof, S. J. Preliminary Multispectral Studies of Soils. Jour. Soil and Water Conservation, Vol. 26, No. 1, Jan.-Feb. 1971.
18. Hanson, D. S., and Dye, R. H. Spectral Signature Recognition. Bendix Technical Jour., Vol. 3, No. 2, Summer-Autumn 1970.
19. Crane, R. B. Preprocessing Techniques to Reduce Atmospheric and Sensor Variability in Multispectral Scanner Data. Proc. Seventh Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, Vol. 2.

PARTNERSHIP IN RESEARCH: A COOPERATIVE REMOTE-SENSING RESEARCH PROGRAM

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To evaluate various remote-sensing systems and analysis techniques for solving specific engineering problems—e.g., soils mapping and detection of seepage zones, landslides, and subsurface cavities—a cooperative remote-sensing research program was developed by the Federal Highway Administration. This program coordinates federal, state, and contract research funded by the Administration and the states. This paper provides an overview of the cooperative research program, describes its development, indicates the type and extent of effort provided by the cooperating groups on the various studies, and briefly summarizes the status of the studies.

•IN RESPONSE to the need to evaluate various remote-sensing systems and analysis techniques and their applicability to highway engineering, the Federal Highway Administration (FHWA) initiated a cooperative remote-sensing research program. This coordinated program includes FHWA staff and administrative contract studies, state research studies using Highway Planning and Research Program (HPR) funds, and also some research efforts by organizations using their own funds (data provided by FHWA).

This paper provides an overview of the cooperative program, describes its development, indicates the type and extent of effort provided by the cooperating groups on the various studies, and briefly summarizes the status of the studies. The details on the establishment of the test sites, the goals of the particular studies, and the results obtained in various aspects of the studies are described in other papers in this Record by Noble, Stallard, West, Wagner, and Dedman and Culver.

REMOTE-SENSING RESEARCH IN THE HIGHWAY FIELD PRIOR TO JUNE 1967

One of the earliest efforts to apply one of the newer aerial sensor systems directly to a highway project was undertaken by the Bureau of Public Roads (now FHWA) in February 1965. HRB-Singer, Inc., under contract to the BPR, performed an aerial infrared survey using a classified sensor over the Rio Atrato Swamp in Colombia, South America. The goal was to locate a feasible route across the swamp. The types of information sought included depth of water, depth to stable foundation, character of sediments, and location of granular materials. The results obtained were negative because of instrument malfunction, adverse environmental conditions, and lack of field control (1).

In March 1965, a study was initiated by the California Division of Highways to evaluate the use of infrared imagery for the investigation of landslides and the location of material sources. This was a cooperative study with FHWA, and HPR funds were used. No imagery was specifically collected for this study. State personnel evaluated infrared imagery collected by other agencies in several different areas of California. The study was completed in early 1968, and the major conclusions reported were that (a) the only promising application noted was that of route location through geothermal areas, (b) security restrictions on instrumentation and imagery were a hindrance to productive work, and (c) much of the equipment used to obtain infrared imagery was in the development stage and subject to considerable operational difficulty (2).

In April 1965, a remote-sensing research program was initiated at Purdue University to determine optimum sensor combinations for the development of master engineering soil plans. This was a cooperative study with the Indiana State Highway Commission and FHWA, and HPR funds were used. It was the first effort in the highway field to evaluate various classified and unclassified airborne remote-sensing systems. The systems evaluated included infrared, radar, and multispectral scanners; multiband camera; and various photographic films.

The first phase of the Purdue study, lasting from April 1965 to December 1966, evaluated the various sensor types over controlled test sites. Also investigated was the development of unique signatures for soils and terrain conditions by means of density measurements on the multispectral imagery—an attempt at semi-automatic interpretation. The major conclusions reported for this phase were that (a) natural aerial color photography was the best single sensor for soils mapping, (b) the optimum combination of sensors for performing detailed engineering soils mapping was simultaneous coverage with multispectral imagery and natural aerial color photography, and (c) the use of multispectral imagery offered the greatest potential for research toward the goal of automatic interpretation (3, 4, 5). The sensors used in this study, with the exception of the aerial cameras, were all classified. This placed a limitation on the publication of the imagery collected by the classified sensors but not on the conclusions derived from the analysis of the imagery.

The second phase of the Purdue study was just being initiated at the time the cooperative remote-sensing research program was developed. Consequently, it was included in the cooperative program.

DEVELOPMENT OF COOPERATIVE REMOTE-SENSING RESEARCH PROGRAM

The results of these early remote-sensing efforts in the highway field as well as research reported in other fields demonstrated the potential value of these systems. They also indicated the need for additional research before many of these sensor systems or analysis techniques could be applied directly to highway projects.

To promote and carry out this needed research, a research program was instituted by the Federal Highway Administration in 1967. The program was entitled "Optimizing Utilization of Natural Resources by Means of Remote Sensing Techniques" and was included as one of the tasks in the National Program for Research and Development in Highway Transportation. The main goal of the program was to investigate the application of various remote-sensing systems for identifying and evaluating natural materials. These systems were to be investigated individually or in combinations both from aerial platforms (to rapidly evaluate large areas) and by field reconnaissance techniques (to evaluate small areas in detail). Concurrent with this effort, computer techniques were to be investigated to aid in the reduction and analysis of the multisensor data.

The accomplishment of a program of this scope required the establishment of several basic criteria.

1. Test sites would have to be established in various parts of the country under a variety of climatic, environmental, and geologic conditions. Conclusions derived from a specific test site would be applicable to local conditions. Generalizing on a regional or national level, however, required the comparison of results derived from several different test sites.
2. Each test site would be a complete unit. That is, a sufficient variety of sensors would be evaluated and certain types of data collected to ensure that a full analysis could be performed—including a computer analysis.
3. The systems evaluated would be those that would generally be available to highway engineers without severe limitations such as security, availability of prototype only, availability of only one source of service, and cost.
4. Liaison would be maintained with various organizations to keep abreast of the latest systems developed. As new sensor systems become available, efforts would be made to incorporate these devices into the test program.

In the establishment of a program of this magnitude, several facts were immediately evident. First, it was not feasible for FHWA to totally fund a program of this size through administrative funds alone. Second, it was improbable that any single highway organization including FHWA had the expertise to evaluate all the various sensors and techniques or the manpower for such an undertaking. Therefore, a prime goal of this program was to develop a cooperative endeavor including FHWA staff efforts, administrative contract efforts, and state efforts either within the HPR Program or with state funds alone.

Fortunately for the development of this program, conditions in the remote-sensing field changed dramatically for the better in late 1967 and early 1968. The data obtained from certain infrared, radar, and multispectral systems as well as some of the systems were declassified, and some of these systems became available commercially. This made it easier to obtain the necessary coverage without the horrendous problem associated with classified data and security clearances. This added impetus to the promotion of the cooperative remote-sensing program.

In the initial planning, it was estimated that approximately 6 to 8 test sites would be required throughout the country in order to properly evaluate the sensor systems on a local and a regional basis. In early 1967, only 2 state HPR remote-sensing studies were in progress: the second phase of the Purdue University study and the California infrared study. The Purdue study met all the desired goals of this program and was included as one of the test sites in the program. The California study was in the process of being phased out and was not included as one of the test sites. Thus, there was a need to establish additional test sites.

PARTICIPATION IN COOPERATIVE RESEARCH PROGRAM

Test Sites

The development of additional test sites required that aid be sought from state highway departments. Several of the states responded to this need; by 1970 cooperative test sites had been established in Kansas, Pennsylvania, and Virginia, and preliminary efforts had been initiated in Maine, Massachusetts, New Hampshire, and New York.

The first test site to be established was in Pennsylvania. Multisensor flights were obtained over this site in May 1969 and again in August 1969. This was followed by the establishment of test sites in Kansas and Virginia where flights were made in 1970. Table 1 gives a brief summary of information on these 3 test sites and the Indiana test site. Included are the types of sensor data obtained, the agencies collecting the data, and a brief description of the test site and the problems investigated.

A cooperative multisensor flight program was carried out in the northeastern states in June 1969. The state highway departments of Maine, Massachusetts, New Hampshire, and New York had selected preliminary test sites in their respective states. The Rome Air Development Center, U.S. Air Force, flew the multisensor mission but was only able to obtain multiband and infrared imagery coverage over selected areas in 3 states—New York, New Hampshire, and Maine. This program was an initial effort to obtain some remote-sensing data coverage for preliminary evaluation prior to the establishment of full-scale test sites. There were some problems encountered with camera operation and test site coverage. Therefore, no extensive analysis of the data could be performed.

Nature of FHWA-Contract-State Participation

The nature of the participation by the various cooperating organizations is complex but flexible. It varies from full support and funding by state HPR funds (Indiana) to practically full support and funding by FHWA (Pennsylvania). The principles guiding the degree of participation by the cooperating organizations are the basic requirements for establishing test sites previously described. Those portions of the program not funded by state funds were funded by FHWA.

The responsibilities of the respective organizations in these cooperative studies are generally as follows:

1. The state highway departments select the test sites, obtain the aerial photographic coverage, provide support for the ground data collection, perform the visual analysis, participate in the preparation of the final report, and in some cases fund the multisensor imagery coverage;
2. FHWA is generally responsible for the overall coordination of the program, aids the states in selecting the test sites, aids the states in the gathering of ground support data and in the visual analysis of the data, participates in the computer analysis of the data, contracts for the collection of the required multisensor imagery coverage when not funded by the states, contracts for the computer analysis of the data by various analysis techniques, and prepares the final report in conjunction with the state; and
3. The contractors responsible for the imagery collection also participate in planning the flight missions, and those that perform the data analysis also participate, where possible, in the collection of the ground support data.

Figure 1 shows the total proposed funding committed to this cooperative program and the amounts expended to June 30, 1971, by the 3 major funding sources: FHWA staff funds, FHWA contract funds, and state HPR funds. Some state non-HPR funds have also been expended on these studies but are not included because of the difficulty in obtaining reliable estimates.

Analysis of Data

One of the major problems in a multisensor project is the analysis of the large quantity of data obtained. For example, in the Kansas test site 74 different sets of data were collected over just 1 test area; a total of 140 different sets of data were collected over 5 test areas. The analysis of this volume of data is a long and tedious process.

As previously indicated, 2 types of analyses are performed: a visual analysis and a computer analysis. The states generally perform the major portion of the visual analysis, and FHWA has the major responsibility for the computer analysis.

The need to develop new techniques to analyze large quantities of data was realized when the cooperative program was being developed. Consequently, FHWA concentrated its major staff and contract efforts in the area of data extraction and analysis by computer techniques. A staff study entitled "Feasibility of Automatically Identifying Terrain Features and Natural Materials From Remote Sensing Data" was instituted in July 1968. This study was programmed for a 5-year period. In this study the major computer analyses are performed under contract to several different organizations. The staff effort includes the selection of the areas to be evaluated and the comparative analysis of the various computer techniques being investigated. The goals of these research efforts are (a) to uniquely identify the pertinent soils and terrain conditions, (b) to develop techniques that will automatically identify and map those features for the entire test areas with a reasonable degree of accuracy, and (c) to try to delineate anomalous areas and determine the reason for the anomaly. Some results of these contract efforts are reported in this Record by West and Wagner.

STATUS OF COOPERATIVE PROGRAM

Indiana

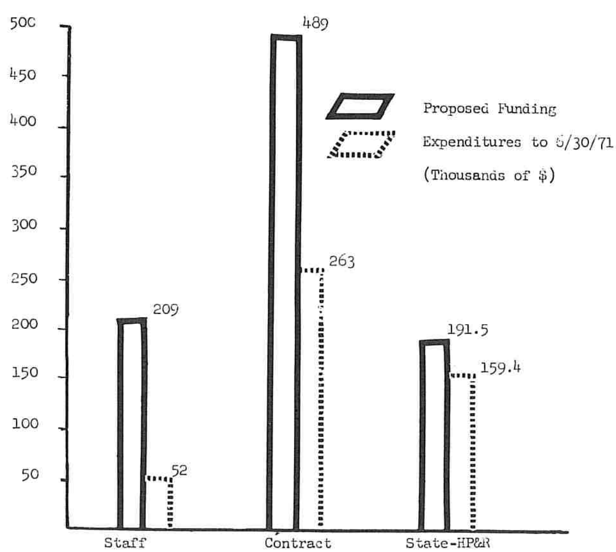
The second phase of the Purdue study was performed during the period January 1967 to June 1969. This phase of the study evaluated the optimum sensor combinations suggested in the first phase for performing engineering soil mapping over a 70-mile (112.7-km) highway project. Also investigated were some of the relative cost aspects of such an approach and the use of digital computer techniques to develop computer-generated maps of soil and terrain conditions. The computer techniques used were those developed by the Purdue University Laboratory for Application of Remote Sensing (LARS). The work in the second phase of the Purdue study was the first attempt to automatically identify and map engineering soils.

Table 1. Cooperative test sites.

State	Number of Sites	Total Length (mile)	Dates Flown	Sensor Coverage Obtained[a]: Aerial[b] Photography	Multiband	Infrared Imagery	Multichannel	Microwave: Radiometry	Microwave: Scatterometry	Agency[c]	Description of Site and Problems Investigated
Indiana	1	70	4-67	X	–	–	–	–	–	ISHC	Humid, temperate climate; rural; glacial, alluvial, eolian, and residual soil and sedimentary rock; soils mapping
			5-67	X	–	–	–	–	–	ISHC	
			4-67	–	–	–	X[d]	–	–	UM	
Pennsylvania	1	48	5-69	X	–	–	–	–	–	PDH	Humid, temperate climate; rural; alluvial and residual soils and igneous, sedimentary, and metamorphic rock; soils and materials mapping and seepage zones
			5-69	X	–	–	X[f]	–	–	UM	
			8-69	–	–	X[e]	–	–	–	RADC	
Kansas	5	47	3-69	X	–	–	–	–	–	KSHC	Humid, temperate climate; rural and urban; alluvial, glacial, eolian, and residual soils and sedimentary rock; soils mapping, subsurface cavities, and pavement condition
			7-69	X	–	–	–	–	–	KSHC	
			9-69	X	–	–	–	–	–	KSHC	
			3-70	X	–	–	–	–	–	KSHC	
			3-70	X	X	X[f]	–	X[f]	X[f]	RSI	
			3-70	–	–	–	X[e]	–	–	UM	
			4-70	X	–	–	X[d]	–	–	UM	
Virginia	1	24	4-70	X	–	–	–	–	–	VDH	Humid, temperate climate; rural; alluvial and residual soils and sedimentary rocks; seepage zones, landslides, and soils mapping
			4-70	X	–	–	X[f]	–	–	UM	
			9-70	X	–	–	–	–	–	VDH	
			9-70	X	–	–	X[f]	–	–	UM	

[a]All photography flown in daytime only. All imagery collected on magnetic tape except that collected by RADC.
[b]At all test sites, black-and-white, natural color, and infrared color were obtained.
[c]ISHC = Indiana State Highway Commission; UM = University of Michigan; PDH = Pennsylvania Department of Highways; RADC = Rome Air Development Center, U.S.A.F. (classified); KSHC = Kansas State Highway Commission; RSI = Remote Sensing, Inc.; and VDH = Virginia Department of Highways.
[d]Daytime.
[e]Nighttime.
[f]Daytime and nighttime.

Figure 1. Funding and expenditures for cooperative remote-sensing program.



The major conclusions reported for this phase of the study were that (a) natural color aerial photography was the best single sensor for preliminary engineering soils mapping, (b) multispectral imagery was a supplement to color aerial photography, and (c) computer analysis of multispectral imagery offered a powerful tool for analyzing the data and automatically distinguishing certain soil and terrain features (6, 7). A report was prepared by Miles (8) summarizing the major aspect of the work performed and the conclusions obtained in the 2 phases of the study.

Pennsylvania

The visual analysis of the data and the delineation of the major land forms were performed by FHWA. Several subareas were selected for detailed investigation along the first 24 miles (38.6 km) of the 48-mile (77.2-km) flight line, and a computer analysis was performed. Under an FHWA administrative contract with the Infrared and Optics Laboratory at the University of Michigan, analog computer techniques were investigated by the use of the SPARC system. Analyses of several subareas were completed, but a final classification by this technique was not attempted. Some of these same subareas were investigated by digital computer techniques under an FHWA administrative contract with LARS; LARSYSAA system was used. West reports in this Record on the results obtained for one of the subareas. A doctoral candidate at Pennsylvania State University selected a portion of the Pennsylvania test site for his research—a cooperative but nonfunded effort with FHWA. The researcher mapped in the field a portion of the site and defined agriculture soil units. He then analyzed the photography and used clustering and digital techniques to perform computer analyses on the multispectral data at Purdue University and Pennsylvania State University. He reported obtaining fairly good results in identifying by computer techniques the various agriculture soils exposed in bare fields (9).

Kansas

Five test areas were flown in the Kansas program: a 27-mile (43.5-km) test area in Jefferson County for soils mapping; a test area in Kansas City, Kansas, for investigating subsurface cavities; and 3 test areas for evaluating pavement conditions. Stallard reports in this Record on the visual analysis of the photography and imagery being performed by the Kansas State Highway Commission. Wagner reports on the investigation of the soils test area in Jefferson County performed by the use of analog computer techniques at the University of Michigan under an FHWA administrative contract.

Density slicing and color enhancement of the Kansas City test area based on relative temperature levels on the 8 to 14 micron imagery are also being investigated by Wagner. The purpose of this analysis is to look for temperature anomalies that are indicative of known subsurface cavities. Digital analysis of the Kansas test areas is in progress at Purdue University under an FHWA administrative contract. No results have been reported to date. Microwave radiometry and scatterometry were also collected over the Kansas test areas. The analysis of these data was performed under an FHWA administrative contract by Resources Technology Corporation of Houston, Texas, and is reported in this Record by Dedman and Culver. The scatterometry data were not analyzed because of the presence of excess noise in the data.

Virginia

The visual data analysis was performed by the Virginia Highway Research Council and is reported in this Record by Noble. Analog and digital computer analysis of the data is in progress at the University of Michigan and at Purdue University under FHWA administrative contracts.

Future Test Sites and Studies

It is evident from data given in Table 1 that the test sites evaluated to date are all in the humid, temperate climate zone. These areas contain a lot of vegetative cover and a minimum exposure of bare soil and rock areas. Test sites are needed in the arid

and semi-arid areas where more bare soils and rock areas are exposed. This requirement may be fulfilled by the establishment of a test site in California, scheduled for the fall of 1972.

The overall goal of the project as previously outlined was threefold: aerial remote sensing, field remote sensing, and computer analysis. The major effort to date has been on the aerial remote sensing and computer analysis phases. Little work has been done in the field remote-sensing area. A new study has been undertaken by the Florida Department of Transportation with the goal of determining the optimum array of remote-sensing techniques for detecting the presence of subsurface cavities and for evaluating the stability of bridge foundations crossing these cavity zones. Both aerial and field remote sensors will be evaluated. There has also been an increased emphasis on field remote-sensing surveys in the recent realignment of FHWA's national research program. The details of the new program are described in the next section.

REALIGNMENT OF FHWA REMOTE-SENSING RESEARCH PROGRAM

A new program entitled "The Federally Coordinated Program of Research and Development in Highway Transportation" has been developed to replace the former program, "National Program for Research and Development in Highway Transportation." The main emphasis of this new program is to concentrate the research efforts on operational problems so that the necessary technology can be developed to meet the needs of the practicing engineer and the results can be implemented.

Within the new program the previous task "Optimum Utilization of Natural Resources by Means of Remote Sensing Techniques" was included within the Project "Techniques to Determine Critical Terrain and Environmental Features by Remote Sensing." Included in this project are two tasks: (a) develop aerial exploration techniques and (b) develop field exploration techniques. The emphasis of the project is to determine terrain and environmental features critical to transportation planning, location, construction, and maintenance with a much greater effort now than previously on field techniques.

The present program is essentially included in the first task in toto. However, it includes other areas that are not in the present program; these areas include the identification and quantification of environmental features and the evaluation of satellite photography and imagery. Critical problems planned for investigation under the second task are delineation of subsurface cavities, determination of the landslide potential of the terrain, and prewarning of slope failures. Some research in this area is already in progress. California is completing a study on monitoring subaudible rock noise as a measure of slope stability—a potentially successful method for prewarning of slope instability. A cooperative staff-contract-state field study was performed in Kansas in August 1971 as a follow-up to the aerial effort for delineating subsurface cavities. Ground-based geophysical equipment, microwave radiometers, and a radar-profiling device were evaluated over several test areas to locate subsurface cavities such as mines and sinkholes. The results of the analysis for some of the test areas will be verified by subsequent drilling.

SUMMARY

This paper describes a joint federal-contract-state research program for evaluating various remote-sensing systems and their application in the highway field—particularly for defining engineering soils and terrain conditions. The background on remote-sensing research in the highway field is discussed, and an account of the development of the FHWA remote-sensing research program is described. A brief summary is included indicating the status of the 4 cooperative studies within this program and the type and extent of effort provided by each of the cooperating groups. Finally, a discussion is included on the new FHWA Federally Coordinated Program of Research and Development in Highway Transportation, its major goals, and the place of the cooperative remote-sensing effort in this new program.

REFERENCES

1. Ory, T. R., and Balmer, H. E., Jr. Infrared Imagery Applications in Determining Highway Engineering Data. HRB-Singer, Inc., State College, Pennsylvania, classified, March 1965.
2. McCauley, M. L. Accomplishment Report on the BPR Financed Research Project: The Use of Infrared Imagery. California Division of Highways, Final Rept. on Study D-5-9, March 1968.
3. Rib, H. T. An Optimum Multisensor Approach for Detailed Engineering Soils Mapping. Joint Highway Research Project, Purdue Univ., Rept. 22, 2 Vols., Dec. 1966.
4. Rib, H. T., and Miles, R. D. Multisensor Analysis for Soils Mapping. HRB Spec. Rept. 102, 1960, pp. 22-37.
5. Rib, H. T., and Miles, R. D. Automatic Interpretation of Terrain Features. Photogrammetric Eng., Vol. 25, No. 2, Feb. 1969, pp. 153-164.
6. Tanguay, M. G. Aerial Photography and Multispectral Remote Sensing for Engineering Soils Mapping. Joint Highway Research Project, Purdue Univ., Rept. 13, June 1969.
7. Tanguay, M. G., Hoffer, R. M., and Miles, R. D. Multispectral Imagery and Automatic Classification of Spectral Response for Detailed Engineering Soils Mapping. Proc., Sixth Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, Oct. 13-16, 1969, pp. 33-63.
8. Miles, R. D. Remote Sensing and Development of Annotated Aerial Photographs as Master Soil Plans for Proposed Highways. Joint Highway Research Project, Purdue Univ., Rept. 15, July 1970.
9. Mathews, H. L. Application of Multispectral Remote Sensing and Spectral Reflectance Patterns to Soil Survey Research. Pennsylvania State Univ., PhD dissertation, Sept. 1972.

UTILIZATION OF REMOTE SENSING IN THE PRELIMINARY AERIAL SURVEY-HIGHWAY PLANNING STAGE IN VIRGINIA

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The purpose of the study was to determine whether infrared technology could be used to delineate soil areas having a high moisture content. Located in Augusta County, Virginia, the study area is mapped geologically, topographically, and pedologically and is heavily farmed and 80 percent nonforested. Data were collected with a multisensor array, including cameras and multispectral sensors. The electromagnetic spectrum was sensed from the violet through the far infrared. Ground truth in the form of radiometer and thermometer readings and color photographs was taken at the time of the flights. The 8.0- to 13.5-micrometer band was sensed during the day and the night and was interpreted for information about those features associated with high moisture content. Correlation of this information with that obtained from the various types of photographs was attempted.

•AMONG THE many problems confronting highway engineers are soils with high moisture contents, areas of poor drainage, areas of potential landslides, and areas of active landslides. Water is central to all these problems. Thus it was hoped that in this study detection of materials with a high moisture content might be accomplished.

The principal purpose of this study as stated in the working plan (3) was to determine whether remote-sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used along a proposed right-of-way to differentiate and delineate the areas that contain high moisture at the ground surface and whether this information could be interpreted to provide knowledge of soil moisture conditions at depth. As a by-product of such a study, information might be generated that would contribute to the knowledge of remotely sensed diagnostic properties of natural materials.

SITE SELECTION AND DESCRIPTION

Several criteria were considered to be important in the selection of a test site. There should be good geologic, pedologic, and meteorologic data available. The areas should be extensively farmed so that large tracts of soil would be exposed. As wide a variety of soil types as possible should be embraced. Based on these criteria, a 12-mile (19.3-km) site in Augusta County was selected. Along this site approximately 80 percent of the land is nonforested and is either cultivated or in pasture.

Physiography and Geology

The great Valley of Virginia passes through the middle of Augusta County. The eastern boundary of the county lies within the Blue Ridge Mountains, and its western quarter is within the folded Appalachian Mountains. The central two-thirds, running approximately northeast-southwest, is underlain by great thicknesses of tilted limestone and shale. Because of the moderate natural fertility of the soils derived from these rocks, the area is extensively farmed.

A northwest-southeast flight line was selected to traverse at approximately 90 deg the northeast-southwest trend of the structural elements. Limestones, dolomites,

and shales of Cambrian and Ordovician age and sands and gravels of Quarternary age were traversed by this line.

The topography along the traverse is rolling and is influenced by the rock types. Table 1 gives the major rock types and materials encountered. Of the several lithologies, at least 2 (Conococheague and the Beekmantown) have very distinct topographic expressions on stereoscopic aerial photographs. The sandstone beds in the Conococheague tend to form ridges, and the deposits of residual chert from weathering of the Beekmantown give rise to conically shaped hills. Most of these bedded rocks dip rather steeply and have differential susceptibility to weathering; that causes the outcrops of bedrock to be long linear (ledgy) features. Travertine forms along some creeks because the creek water contains sufficient calcium and bicarbonate ions in solution such that the calcium carbonate of the travertine forms when creek water evaporates. There is significant solution of limestone occurring within the area. Incipient karst topography occurs at the northwest end of the traverse where there are 2 small sinkholes. The existence of underground cavities in these areas is a distinct possibility.

Zones of fracture such as the Pulaski-Staunton Fault, joints along the crests of folds, and abandoned and filled channels on the flood plain are areas that might localize water.

Soil Types

Descriptions of the soils most commonly occurring within the study area are given in Table 1 (2). The data are necessarily generalized.

The soils encountered reflect their genesis, which is a function of parent material, climate, relief, plant and animal life acting on and within soil, and time subjected to soil-forming processes. Thus, the soils reflect the presence of chert and quartz sand in the Conococheague limestone and sandstone, chert in the Beekmantown dolomite and the clay, and silt in the Martinsburg shale. The climate is temperate with an average annual precipitation of 37 in. that is relatively evenly distributed over the year. Such conditions are conducive to chemical attack of limestone and dolomite. Therefore, the greatest soil thicknesses occur over portions of the carbonate rocks. Where slopes are level to gentle, erosion is minimized, and there is sufficient time to develop thick, mature soil profiles over the carbonates.

GROUND CONTROL DATA

The staff of the Photogrammetry Section of the Virginia Department of Highways prepared an uncorrected photomosaic at a scale ratio of 1 to 24,000 for field use and also acquired the aeronautical charts for the consultant. Topographic maps and geologic maps of the 7.5-min series were obtained from the Virginia Division of Mineral Resources. The Soil Conservation Service of the U.S. Department of Agriculture was preparing a soil survey report of Augusta County and kindly made the preliminary draft available (2). Very useful data were obtained in the form of soil boundaries on a black-and-white aerial photo format; the soil descriptions contained data on the physical properties of the soils and information on their agricultural, forest, engineering, and urban suitability.

GROUND TRUTH MEASUREMENTS

Ground truth measurements are a necessary complement to the data taken during aerial flights. Knowledge of the surface conditions at the time of the flight enhances the interpretation of the data.

Many parameters could have been checked at the time of the flight. However, checking of a parameter was restricted by the time and the number of personnel. Consideration of equipment and personnel dictated that parameters such as soil moisture content and precise meteorological conditions not be checked. Thus, ground truth checks were organized so as to acquire the greatest amount of information on a few parameters judged to be the most useful in terms of correlation with the flight data. Ground temperature and color photographs were taken, and visual estimates of meteorological conditions were made.

The traverse was field-checked to establish, on the basis of previous years' farming practices, potential ground truth sites that might be bare at the time of the flight. As many types of material and conditions as possible were selected. Aside from the ground truth sites in relatively level fields, a site for a water reading was established just off a bridge over Christians Creek because of the minimum diurnal fluctuations in the water's temperature. Several checkpoints that were established for reading embankments were affected to a lesser degree by solar radiation and nocturnal cooling than were the level fields. The sites had to be located close to the roads because cars and trucks were used as transportation to them.

The day before the flight a final check of the traverse was made. Recent changes in field conditions were noted. Where necessary, the sites of ground truth checks were changed. Stakes were placed to serve as reference points so that the instrument man would take measurements at approximately the same location.

Temperature Measurements

For both the day and the night flights, 2 crews composed of FHWA and Virginia Highway Research Council personnel took surface temperatures at the selected sites. Both contact thermometers and remote infrared radiometers were employed. The surface thermometer was placed on the soil surface, the stem of the dial thermometer was placed just under the surface, and the radiometer was focused on the soil surface but scanned over a relatively large area. These readings were recorded along with site notation, time, and instances when the aircraft was overhead.

Color Photographs

During the day flight, Virginia Highway Research Council personnel, equipped both with 35-mm cameras loaded with Ektachrome film and with 7.5-min quadrangle topographic maps for locating sites, photographed specific fields and conditions on selected segments of the traverse. The purpose of this photography was to provide reasonably close-up photographic evidence of ground conditions at the time of the flight. Some of the photographers had very little experience with the type of cameras provided, and the photographs were of necessity taken in a hurried manner. Results of this photography demonstrated that the best photographs were taken with the most automatic cameras. Use of a hand-held light meter resulted in underexposures.

PLANNING OF FLIGHT

Selection of Sensors and Film Types

The wavelength bands within the electromagnetic spectrum selected for electronic sensing are given in Table 2. Wavelength bands were chosen so that the visible and infrared spectra were covered. At night, the only wavelength bands sensed were the middle and far infrared. The films chosen for the photography are given in Table 3; the personnel of the University of Michigan used the 70-mm film, and the Virginia Department of Highways used the 9- by 9-in. film.

The purpose of the aerial photography was to provide the usual type of data to which the photo interpreter is accustomed. Normal black and white, Ektachrome color, infrared black and white, and infrared color permitted the evaluation of which parameter a specific film showed best and also permitted the combination of the several photographic records so that information on a specific parameter might be better documented.

As a means of calibration, eight 20- by 40-ft, coated, canvas panels of known reflectances were staked in a relatively level field. Five of the panels were of a gray tone and had reflectances ranging from 0 to 80 percent in 20 percent increments. The other 3 panels were red, blue, and green.

Flight Times

Initially it was hoped that one flight could be made during the wet spring and that the other flight could be made after a dry summer or early fall so that the effect of the

Table 1. Description of certain soils in Augusta County.

Soil Description	Depth (ft)	Drainage Class	Permeability	Susceptibility to Erosion	Depth of Seasonal High Water Table (ft)	Genesis
Dandridge silt loam—dark brown to yellowish brown, very friable surface soil, silt loam or shaly silt loam	1 to $1^3/_4$	Well to excessive	Moderately rapid	High	4 plus	Residual
Frederick—yellowish brown to red in B, friable surface soil, silt loam to clay in B	4 to 30	Well	Moderate	Moderate to high	6 plus	Residual
Floodplain and terrace soils: Braddock, Laidig, Melvin, Monongahela, Newark, Purdy, Tyler—yellowish brown to dark gray, friable to very friable surface soil, sandy to silt loam	6 to 10	Relatively poor	Low to moderate	Low to moderate depending on slope and regional relief	0 to 3, with ponding on floodplain	Transported

Table 2. Spectral bands sensed by electronic sensors.

Time	Spectral Color	Wavelength Band (um)	Field of View (deg)
Day	Violet	0.40 to 0.44	80
	Blue	0.44 to 0.46	
		0.46 to 0.48	
		0.48 to 0.50	
	Green	0.50 to 0.52	
		0.52 to 0.55	
		0.55 to 0.58	
	Yellow	0.58 to 0.62	
	Orange	0.62 to 0.66	
	Red	0.66 to 0.72	
	Near infrared	0.72 to 0.80	
		0.80 to 1.0	
		1.0 to 1.4	
	Middle infrared	1.5 to 1.8	37
		2.0 to 2.6	
		2.0 to 2.6 low gain	
	Far infrared	8.0 to 13.5	
		8.0 to 13.5 low gain	
Night	Middle infrared	4.5 to 5.5	37
		4.5 to 5.5 low gain	
	Far infrared	8.0 to 13.5	80
		8.0 to 13.5 low gain	
		8.0 to 10.0	
		10.0 to 11.0	

Table 3. Film and camera types.

Film				
Name	Type	Size	Filter	Camera
Black and white	2402	70 mm	W12	P-2
Black and white infrared	2424	70 mm	89B	P-2
Ektachrome	8442	70 mm	1A	KB-8
Color infrared	8443	70 mm	W15	P-220
Black and white (XX)	2405	9 in.	W12	Wild RC-8
Ektachrome	8442	9 in.	Antivignetting	Wild RC-8
Color infrared	8443	9 in.	W12	Wild RC-8

moisture contrast might be observed. Early April was chosen for the wet season flight because little if any snow cover was expected and the trees were not expected to be beyond the budding stage. The time for the day flight considered most desirable was between 10:00 a.m. and 2:00 p.m. The object was to have maximum sun, minimum shadow, and minimum cloud cover. The primary constraint on the timing of the night flight was that all residual energy absorbed during the day should have been dissipated so that the only radiation coming from the earth would be that which was characteristic of the material and its temperature. The night air was quite cool (approximately 0 C), and an equilibrium condition was reached well before the flight time of 11:00 p.m.

The second flight was planned for mid-November; but, because of equipment breakdown, it was postponed until mid-December. The delay was fortuitous in that few fields were bare in November, but winter plowing bared numerous fields by the December flight date. The times during the day for the flights were similar for the reasons mentioned earlier. Unfortunately, soil conditions were much wetter than desired, and a low sun angle caused pronounced shadows.

Post-Flight Data Check

After completion of the day and night flights, the consultant recommended checking several of the electronically sensed wavelength bands in order to verify that data were acquired and that they were on the desired flight line.

Length and Elevation

The general choice of location for the traverse ensured such variety in materials and terrain that the precise length of the traverse was somewhat a matter of convenience. Flying the traverse at 2 altitudes was considered useful so that interpretation of data with different degrees of resolution could be compared and a judgment could be made on the value to highway needs of flying higher with poorer resolution but greater areal coverage. Inasmuch as the reels of magnetic tape on which the data were recorded would accommodate 24 flight-miles (14.9 km) of data, it was decided to make the flight line 12 miles (7.5 km) long. Thus flying 2 altitudes would use a roll of tape.

Because the purpose of the study was to judge whether multispectral remote sensing was applicable to highway planning and engineering, a decision was made to fly the flight line at an elevation above mean ground altitude that would amply cover the minimum right-of-way required for an Interstate highway. Safe operation of the aircraft was also a consideration, and the lowest elevation above mean ground altitude that would cover the right-of-way was too low for safety. Thus, elevations of 2,000 and 5,000 ft above mean ground altitude were chosen. These elevations gave a minimum and maximum ground coverage of 1,338 and 8,390 ft for the 37- and 80-deg angle fields of view respectively.

Details of Preparation

Coordination between the crews collecting ground truth data and the flight crews was important. Therefore, the following procedures were utilized:

1. A local airport large enough to accommodate a C-47 aircraft and as close to the project area as possible was used as a base of operations;
2. Telephone contact was maintained between the ground and the flight crews up to flight time for last-minute consultations;
3. A signal was arranged by which the flight crew could indicate to the ground crews that the mission was completed; and
4. Radio contact was possible among several highway department vehicles and the department plane.

There were several other preparations worthy of note. One was the placement of strobe lights along the flight line as an aid to night navigation. The other was that notifying the local police about the impending night activity saved the citizens some confusion and alarm.

ANALYSIS OF DATA

Format

The electronically sensed data were recorded on magnetic tape. In addition, the data on the tape were converted to gray tone images and presented on 70-mm film (negatives and prints) for visual interpretation. The gray tone images had the advantage of being in a form that was familiar to most people, but they were deficient in that the film did not have sufficient tones of gray to represent the many variations that the magnetic tape was capable of recording (1).

Duplicate tapes, negatives, and prints of both the spectral data and the 70-mm film exposed by the consultant and the 9- by 9-in. film used by the department were supplied to the council and the FHWA. The council had prime responsibility for the visual interpretation of the data; the FHWA planned to concentrate its interpretive effort on the computerized analysis of the data as recorded on the magnetic tapes.

Approach to Visual Analysis

It was decided to choose specific features and conditions on the films for investigation. These included sinkholes, faults, filled oxbow lakes, channel cutoffs, and leakage from reservoirs—all known to have high moisture. This approach was taken because the principal purpose of this study was to determine whether remote-sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used to differentiate and delineate the areas along the proposed right-of-way that contain high moisture at the ground surface. In addition, this approach was taken because there were so many data that to interpret them all as fully as possible would have taken more time than was available.

Previous studies by Rib and Miles (5) and Tanguay and Miles (6) concluded that infrared imagery cannot be used as a primary source for engineering soils mapping because of its small scale, poor resolution, and lack of stereoscopic viewing capabilities. Its primary value was that it provided supplementary information not obtainable by any other means and converging evidence that aided in the interpretation of soil conditions from the various types of photographs available. Thus, it was decided to study both the 8.0- to 13.5-micrometer band sensed during the day and the night and the 4.5- to 5.0-micrometer band sensed during the night to determine what could be ascertained about those features expected to have water associated with them. After as much information as possible had been garnered from the infrared imagery, the various types of photographs available were examined, and the information interpreted from the 2 types of sensed data was compared.

RESULTS AND DISCUSSION

Surface water had strong emittance during the night because of its relative warmth and low emittance during the day because of its relative coolness; therefore, bright and dark images respectively were on the film strips. Natural and artificial ponding and drainageways containing surface water were easily detected on the night-sensed 8.0- to 13.5-micrometer band. Features that could be observed on black-and-white and Ektachrome color prints, but could not be interpreted as containing water, could be so interpreted on all the night-sensed, infrared imagery but in differing degrees. Color infrared also provided a good indication of surface water.

Soils with a high moisture content were detected in comparisons of the black-and-white photographs and the daytime and the nighttime imagery in the 8.0- to 13.5-micrometer band (thermal infrared). Dark images on the photographs may represent dark colored soils, various types and densities of vegetation, or soils with a high moisture content. On the daytime imagery, relatively dry dark soils have a light-toned image because the dark material absorbs more energy and is at a higher temperature than the lighter colored materials and emits a greater intensity of infrared radiation. Vegetation, surface water, and materials with a high moisture content have dark images because transpiration and evaporation respectively keep the materials relatively cool; thus, they are weak emitters. A check of the various types of photo-

graphs can confirm the presence or absence of vegetation, its color (Ektachrome color), and its vigor (infrared color). The absence of vegetation confirms the presence of soils with high moisture content. The presence of vegetation necessitates inspection of the nighttime imagery. On nighttime imagery, relatively dry soils have images of various tones of gray representative of the basic nature of the materials. Water is the lightest because it is relatively warm and emits strongly. Trees are also light but not so light as the water, and the low vegetation remains dark. Therefore, the coincidence of a dark photographic image, a dark daytime thermal infrared image, and a light nighttime thermal infrared image indicates the presence of high moisture content material. Examples of the black-and-white photographs and the daytime and nighttime thermal infrared imagery are shown in Figure 1. Despite some intermittently cloudy and rainy weather for about 2 weeks prior to the December flight and showers the day of the night flight, the floodplain region of the South River was much drier than it was at the time of the April flight.

There was a closed but rather freely draining sinkhole at the northwest end of the traverse. Several of the night-sensed infrared bands contained a medium-gray image that coincided with the location of the sinkhole. This image was best differentiated on the film strip of the 10.0- to 11.0-micrometer band. At least 2 other medium-gray spots coincided with depressions that appeared to result from the same type of collapse associated with sinkholes. A group of 9 irregularly shaped images of a similar gray tone was detected on the 10.0- to 11.0-micrometer band for an area 2 to $2\frac{1}{2}$ miles southwest of the northwest end of the traverse (Fig. 2). There was nothing distinctive about the daytime imagery for this area. The area was somewhat removed from the network of county roads and had not been observed on the ground. A check of the topographic map showed 3 depressions in the area. A field check confirmed that sinkholes and depressions of varying reliefs existed at the sites of 7 of the medium-gray images. The other 2 areas were high on slopes and did not show any depression. Initially it was expected that the depressions would be wetter and warmer than the surrounding areas; thus they would have a stronger emittance and have a lighter gray image than the surrounding, drier and cooler area. The opposite finding might be explained by the occurrence of cavities that insulated the surface from the normal heat flow in the area and caused the depressions to be cooler than the surrounding area. The darker image might also be explained by a higher density of vegetation within the depressions, but no evidence for such an interpretation was found on the Ektachrome color or infrared color prints.

CONCLUSIONS

1. Nighttime thermal infrared imagery, the 8.0- to 13.5-micrometer band, is the best band for the remote detection of surface water. It has great value in establishing water-soil boundaries, determining which drainageways are carrying water, and locating surface water obscured by the image of vegetation on the other imagery and on the photographs.
2. A combination of photographs and daytime and nighttime thermal infrared imagery can be used to detect and delineate soil areas that have a high moisture content. However, currently the principal investigator can detect only zones of extremely high moisture content, such as areas that are in proximity to surface water or areas that coincide with drainageways.
3. It appears that photographs and daytime and nighttime thermal infrared imagery may be used as a guide to the location of subsurface cavities. These cavities cannot be verified by simple visual observation in the field as were the other phenomena, but the sensor data and the presence of sinkholes strongly suggest their existence.

ACKNOWLEDGMENTS

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Figure 1. Black-and-white photographs and daytime and nighttime thermal infrared imagery (arrows point to zones of high moisture content).

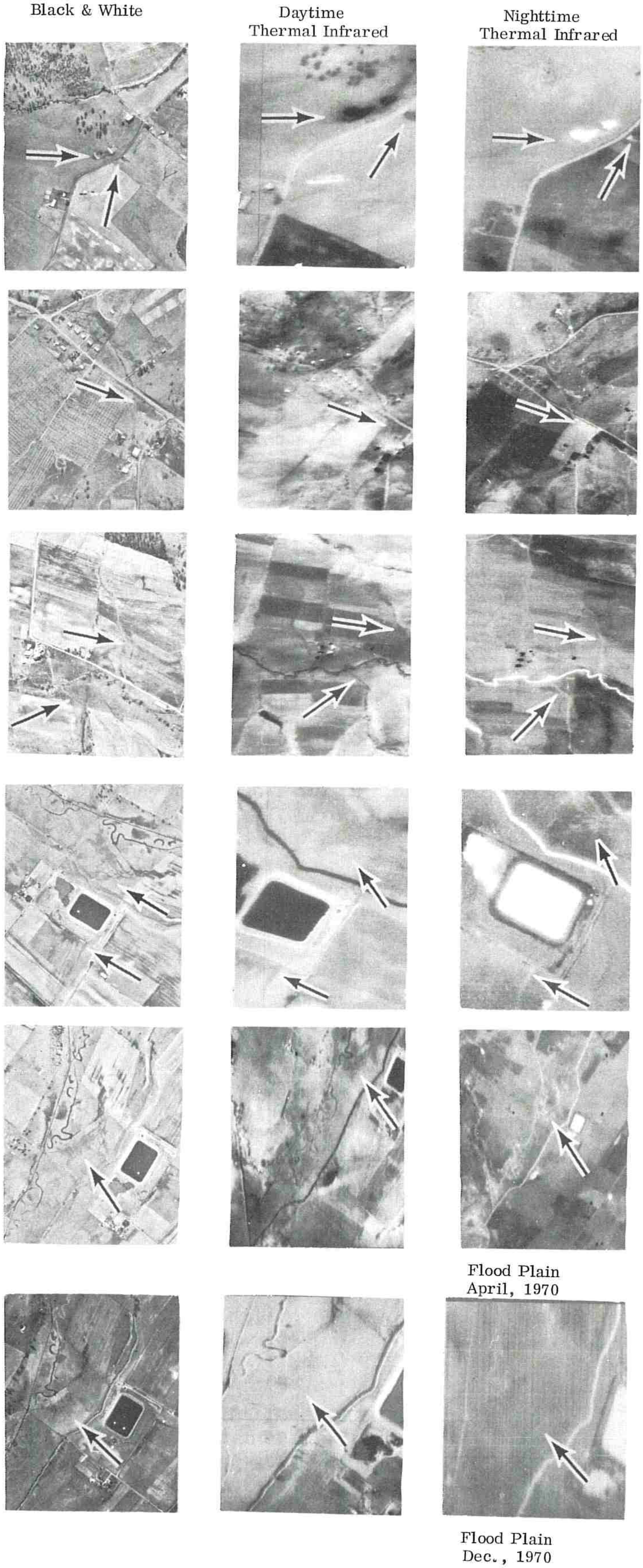
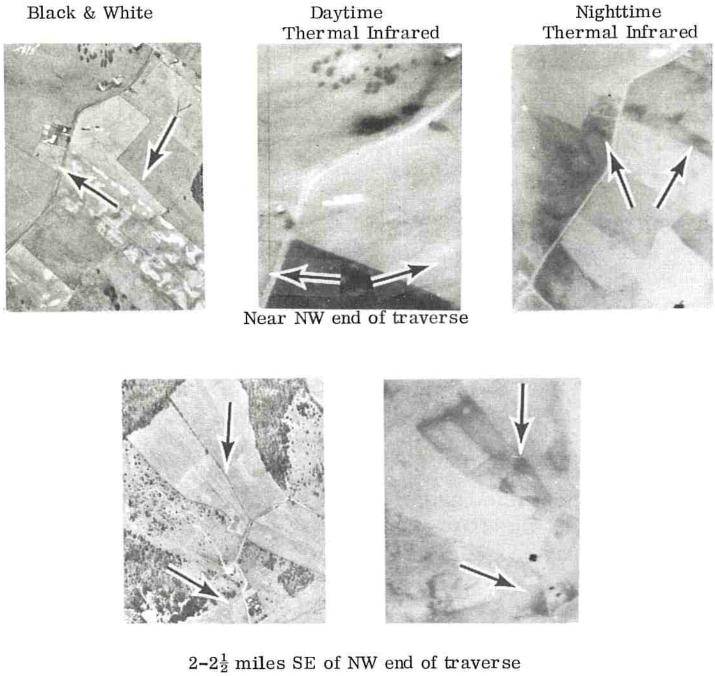


Figure 2. Gray images that coincided with depressions (arrows point to features).



This research was conducted under the general direction of J. H. Dillard, and was financed by HPR funds administered by the Federal Highway Administration. Personnel of the University of Michigan were engaged as consultants for the remote-sensing flights. Personnel of the Virginia Highway Research Council had responsibility for visual interpretation of the data.

REFERENCES

1. Hasell, P. G., Jr. Personal communication, 1970.
2. Hockman, J., et al. Soil Survey of Augusta County by Soil Conservation Service. U.S. Dept. of Agriculture, 1969.
3. Noble, D. F. Utilization of Remote Sensing in the Preliminary Aerial Survey—Planning State. Virginia Highway Research Council, Working plan, 1969, 15 pp.
4. Rib, H. T. An Optimum Multisensor Approach for Detailed Engineering Soils Mapping. Joint Highway Research Project, Purdue Univ., Rept. 22, 2 Vols, 1966, 406 pp.
5. Rib, H. T., and Miles, R. D. Multisensor Analysis for Soils Mapping in Remote Sensing and Its Application to Highway Engineering. HRB Spec. Rept. 102, 1969, pp. 22-37.
6. Tanguay, M. G., and Miles, R. D. Multispectral Data Interpretation for Engineering Soils Mapping. Highway Research Record 319, 1970, pp. 58-77.

USE OF REMOTE SENSORS IN HIGHWAY ENGINEERING IN KANSAS

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Many papers have been written concerning the domestic use of various types of remote sensors; however, few describe specific applications of remote sensors to highway engineering problems. The purpose of this paper is to describe the remote-sensing program conducted by the State Highway Commission of Kansas in cooperation with the Federal Highway Administration and to present the results of visual interpretation of the data collected. Descriptions are given of methods of collection and types of data, including frequency and type of ground observation data. Data collected on magnetic tape, to be reduced and analyzed by computer, are described; however, no findings are presented. Results of visual interpretation of data indicate that the combined use of color aerial photography and infrared imagery (8- to 14-μm, nighttime, high-altitude) renders the most distinctive evidence for detection, evaluation, and mapping of engineering soil groups.

•THIS investigation was conducted by the State Highway Commission of Kansas in cooperation with the Federal Highway Administration to determine the value of certain remote sensors when applied to highway engineering problems in eastern Kansas. Three engineering problems were investigated: evaluation of the condition of concrete pavement, detection of subterranean voids, and detection and mapping of engineering soil groups. The specific objectives were as follows:

1. Evaluate sensor data combined with aerial photography in the evaluation of concrete pavement performance and the detection of concrete stains;
2. Determine what combination of aerial photography and imagery would render a distinctive signature for various types of soils and materials;
3. Determine whether the cost of remote sensors can be justified at this stage of development for soil and materials mapping in Kansas; and
4. Determine the best combination of photography, within the capability of the State Highway Commission of Kansas, for soils and materials investigations.

This report describes the results obtained in the investigation for the detection and mapping of engineering soil groups.

CONTRACTORS

Four contractors were engaged to gather, reduce, and analyze remote-sensing data over one or more of the test sites.

1. Remote Sensing, Inc., Houston, Texas, was engaged by the State Highway Commission of Kansas to gather airborne remote-sensing data over the 5 test sites. The equipment included Wild RC-8 aerial camera, plus X panchromatic film; RS-14 dual-channel infrared scanner, 3- to 5.5-μm and 8- to 14-μm range; 13.3 GHz scatterometer; 13.7 GHz microwave radiometer; and Hasselblad 4-camera cluster for narrow-band photography. The infrared, scatterometer, and microwave-radiometer data were collected on magnetic tape. Imagery was available for the 8- to 14- and 3- to 5.5-μm infrared range.
2. Peter E. Chapman and Peter A. Brennan, Consultants, Reno, Nevada, were engaged by Remote Sensing, Inc., as subcontractors to gather spectral-reflectance data

to compile spectral albedo curves in order to select film-filter combinations for the Hasselblad camera cluster for use in soil discrimination. An ISCO model spectroradiometer was used to take values in a 2-phase operation that included the visible range (380 to 750 nanometers) and near infrared (750 to 1,550 nanometers).

3. Resources Technology Corporation, Houston, Texas, was engaged by the Federal Highway Administration to reduce and analyze the remote-sensing data collected over all sites on magnetic tapes by Remote Sensing, Inc.

4. Under separate contract, the Federal Highway Administration engaged the Willow Run Laboratories, University of Michigan, Ann Arbor, to obtain multispectral data over 3 of the test sites. Results of this facet of the investigation will be released by the Federal Highway Administration. Some of the results obtained by the University of Michigan on the computer analysis of one of the test sites are reported in this Record by Wagner.

TEST SITES

Five test sites were selected. Test sites 1, 2, and 3 were used for concrete pavement evaluation; test site 4 was used for the detection of subterranean voids; and test site 5 was used for the detection and mapping of major engineering soil groups.

This report will only discuss the results obtained for the detection and mapping of major engineering soil groups. Consequently, the subsequent discussions will be limited to the investigations of site 5.

Test site 5 is a 27- by 1-mile segment of land in Jefferson County, Kansas. The area is characterized by interbedded Pennsylvanian limestone and shale overlain by Kansan glacial drift; residual soils are prominent along valley walls of major drainage channels. Loessial type of soil caps the high terrain in the northern area, and alluvium is encountered in the Kansas River valley on the south end of the site as well as in the valleys of major drainage channels throughout the area.

PREVIOUS WORK IN AREA

A construction materials inventory of Jefferson County by photo interpretation was completed by the State Highway Commission of Kansas in 1968, and several preliminary soil surveys have been conducted along centerlines of major highways in the corridor area. No extensive engineering soil mapping has been accomplished in the area by ground-survey methods or with remote sensor and aerial photography. The Soil Conservation Service of the U. S. Department of Agriculture has mapped approximately 80 percent of the corridor area for agricultural purposes.

DATA COLLECTION

Planning Photography

On March 17, 1969, black-and-white panchromatic photography was flown at a scale of 1:18,000. It was used to plan the remote-sensing mission and to conduct initial landform classification. Color Ektachrome was flown in August 28, 1969, at scales of 1:2,000 and 1:10,000, and color infrared was flown on October 5, 1969, at the same scales. This photography was used to study the area with differing vegetative conditions and to assist in the initial landform classification.

Ground Reconnaissance

Ground reconnaissance of the test site was completed by January 1970. Soils in each major landform were evaluated according to color (Munsell color notations), grain size, plasticity indexes, and parent material. Within the various landforms, more than 100 stations were selected as sites for collecting ground-observation data and for taking ground-reflectance readings. The latter would be used to select film-filter combinations for narrow-band photography.

Ground-Reflectance Readings

On March 14 and 15, 1970, consultants Chapman and Brennan took ground-reflectance readings using an ISCO model SR spectroradiometer. Sky and ground readings were taken at each station. Readings were taken at 0.025-μm increments between 0.4 and 0.75 μm (visible range) and at 0.05-μm increments between 0.8 and 1.0 μm (near-infrared range). Readings were taken on existing dry ground, and soil-moisture samples were taken at each station. Subsequently, the ground was saturated, and readings were taken to ascertain the decrease in soil-reflectance ability due to wet conditions.

The purpose of the narrow-band photography was to enhance the contrast between major engineering soil groups. Reflectance readings were taken primarily on soils formed in the Kansas River alluvium; however, readings were taken on glacial and loessial soils and residual soils derived from Pennsylvanian bedrock. These soil types were referred to as upland soils. Alluvial and upland soils were evaluated separately, inasmuch as the respective landforms were easily differentiated on aerial photography.

Figure 1 shows reflectance data for representative readings for alluvial-soil units. Figure 2 shows reflectance data for representative readings for upland-soil units. The greatest albedo spread occurred in the red and near infrared; however, several of the curves crossed in the yellow, green, and blue portion of the spectrum. Although reflectance was less and the albedo spread between major soil groups was reduced on wet samples, the greatest albedo difference still occurred in the red and near-infrared portion of the spectrum.

Most soil-mapping problems were anticipated in the alluvial soils, and most reflectance readings were concentrated in this area. The variation in reflectance within the same alluvial soil type is shown in Figure 3. The albedo spread among the soil types was great enough so that no overlap occurred at any wavelength.

Inasmuch as the greatest albedo spread occurred in the red and near infrared, the film-filter combinations were selected to concentrate the narrow-band photography in this portion of the spectrum. Figure 4 shows film and filter selection for each of the Hasselblad cameras.

Collection of Remote-Sensing Data

On March 23, 1970, the daytime remote-sensing mission was flown by Remote Sensing, Inc. A Fan Jet Falcon aircraft was used and was equipped with an aerial metric camera, a dual-channel infrared scanner, a 13.3-GHz scatterometer, a 13.7-GHz microwave radiometer, and a 4-camera cluster of Hasselblad cameras. Data were collected at 1,000 ft and 5,000 ft above terrain. At approximately the same time, color Ektachrome and color infrared photography was flown by the State Highway Commission of Kansas at altitudes of 1,000 and 5,000 ft above the terrain. A Wild RC-8 aerial camera and a Cessna 206 aircraft were used.

In the early morning hours of March 24, the nighttime remote-sensing mission was flown. Radiometer, scatterometer, and infrared data were collected on magnetic tape at altitudes of 1,000 and 5,000 ft above the terrain. Table 1 gives the data collected.

Ground-Observation Data

Eight 2-man crews gathered ground-observation data prior to, during, and immediately after the day remote-sensing mission, and 3 crews collected data during the night flight. During the day mission, 6 crews collected surface and subsurface (13-in. depth) soil-moisture samples, recorded surface and subsurface (13-in. depth) soil temperatures, and took ground color photographs at designated stations. More than 200 soil samples and 100 ground photographs were taken. Personnel from the Federal Highway Administration took ground radiometer (8- to 14-μm range) readings at designated stations. A ground-resolution target was placed in the center of the flight line in order to evaluate the quality of the aerial photography.

Except for ground photography, similar but lesser amounts of data were collected during the night mission. Five rotating amber beacons were stationed along the flight line of the test site to guide the aircraft. Aluminum foil targets, 10 by 10 ft, were placed at the beacon stations to provide control points for the radiometer data.

Figure 1. Representative reflectance readings for alluvial soils.

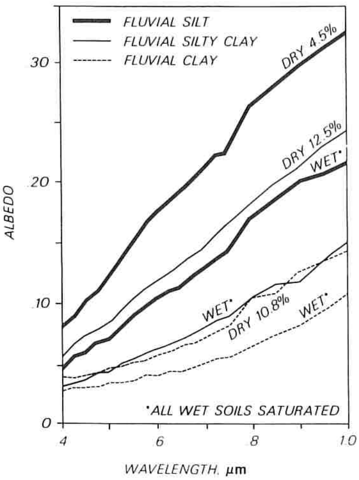


Figure 2. Representative reflectance readings for upland soils.

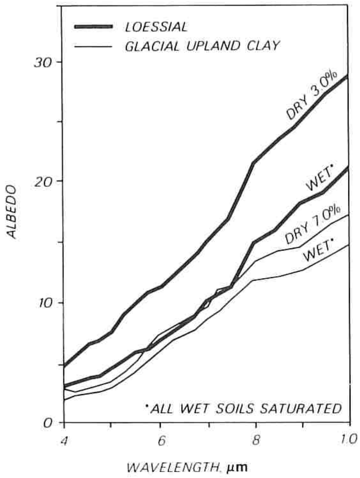


Figure 3. Variation of reflectance of major alluvial soils.

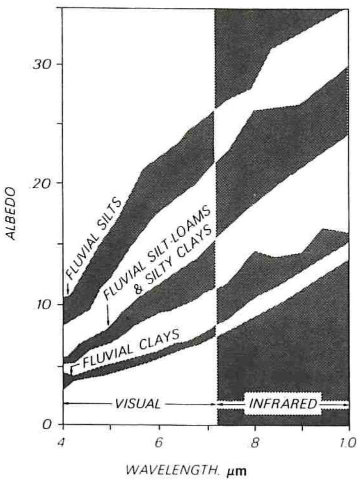


Figure 4. Film-filter selection for narrow-band photography.

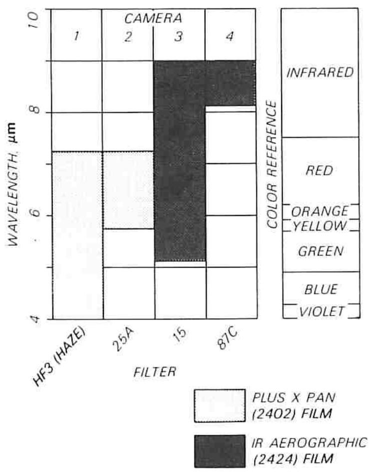


Table 1. Remote-sensing data gathered over test site 5.

Data	Date	Altitude or Scale
Black and white panchromatic photography	3-17-69	1:18,000
Color Ektachrome photography	7-28-69	1:10,000 and 1:2,000
Color infrared photography	9-5-69	1:10,000 and 1:2,000
Black-and-white panchromatic photography	3-23-70	1:10,000 and 1:2,000
Color Ektachrome photography	3-23-70	1:10,000 and 1:2,000
Color infrared photography	3-23-70	1:10,000 and 1:2,000
Narrow-band photography 70 mm, 0.4 to 0.72 μm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.58 to 0.72 μm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.52 to 0.9 μm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.8 to 0.9 μm	3-23-70	1:8,000 and 1:32,000
Infrared 8- to 14-μm imagery, day	3-23-70	6,000 and 1,000 ft
Infrared 3- to 5.5-μm imagery, day	3-23-70	6,000 and 1,000 ft
Infrared 8- to 14-μm imagery, night	3-24-70	6,000 and 1,000 ft
Infrared 3- to 5.5-μm imagery, night	3-24-70	6,000 and 1,000 ft
13.3 GHz scatterometer data on magnetic tape, day	3-23-70	6,000 and 1,000 ft
13.7 GHz radiometer data on magnetic tape, day	3-23-70	6,000 and 1,000 ft
13.3 GHz scatterometer data on magnetic tape, night	3-24-70	6,000 and 1,000 ft
13.7 GHz radiometer data on magnetic tape, night	3-24-70	6,000 and 1,000 ft

DATA ANALYSIS

The scope of this discussion is limited to the results obtained by the State Highway Commission of Kansas from the visual analysis of photography and imagery taken over test site 5 in Jefferson County. Data collected on magnetic tapes over all sites are being reduced and analyzed by contractors engaged by the Federal Highway Administration under separate contract. A final report to be released jointly by the State Highway Commission of Kansas and the Federal Highway Administration will present final results of this aspect of the research project.

Planned Method of Operation

For this study, the interpretation and mapping efforts were concentrated in 3 separate areas that represented the different geological conditions in the test site. Initial interpretation of the soils was accomplished on stereopairs of black-and-white panchromatic photography at a scale of 1:5,000. Soil maps were prepared in pencil in order that modifications could be made as other forms of data were analyzed. Color and color infrared photography were then analyzed along with narrow-band photography. Infrared imagery (8- to 14-micrometer range) was analyzed last. Available Soil Conservation Service information was used to assist in the interpretation in a portion of each test section.

Each map unit designation included 6 items:

1. Landform classification,
2. Surface soil classification according to the Unified Soil Classification System,
3. Composite soil texture according to State Highway Commission of Kansas classification system,
4. Depth to bedrock,
5. Depth to groundwater table, and
6. Slope.

Once interpretation of data was completed and the soil maps completed, soil samples were taken in each major soil map unit on a statistical basis. The field sample data along with Soil Conservation Service information were to serve as a standard to evaluate the soil mapping process.

Interpretation and Correlation of Data

The detailed analysis and results of this phase of the study with the supporting data are included in an interim report by Stallard and Myers (1). The results and conclusions are summarized here.

Remote-Sensing Data

Broad landform relations were delineated on conventional black-and-white photography, particularly at the smaller scale. Soil groups were differentiated with varying degrees of accuracy through the use of clues provided by drainage patterns, land use, tonal contrasts, and slope changes. Narrow-band photography (no stereovision) provided similar information and added some contrasts in vegetation. Best tonal contrast was observed on photographs taken in the 0.58- to 0.72-μm band, which utilized a Wratten 25A filter.

Color photography (color transparencies) provided modifications to features delineated from the interpretation of black and white, especially on boundaries of soils that became more shallow downslope. Soil color changes were useful to place boundaries in areas where no tonal contrasts were evident on black-and-white photography. In bare fields, color photography contributed a great deal of detailed information concerning soil depths and types. Color was extremely helpful in differentiating residual limestone soil (a reddish color), unweathered glacial drift (a mottled-reddish color), and loessial soils that capped high terrain.

Color infrared photography provided contrasts similar to those provided by conventional color photography. In areas where contrasts on bare soils were useful in mapping,

the color rendered a more distinct boundary. However, marked contrasts may be seen in differences in the growth of vegetation, particularly in different types of crops.

Marked differences were observed between the day and the night infrared imagery (8- to 14-μm range). The day imagery shows contrasts attributable to differences in vegetation and soil conditions (Fig. 5). Some very interesting contrasts were observed on the night imagery in one of the test areas (Oskaloosa), inasmuch as they did not coincide with any delineations or patterns observed on any of the other types of photography or imagery. Thermal units detected tend to indicate depths to bedrock or to the groundwater table, which acts as a strong thermal reservoir in areas of most intense radiation. This tentative conclusion is based on field drilling and probing that was accomplished along lines A-A′, B-B′, and C-C′ shown in Figure 5. An example of one of the profiles, B-B′, is shown in Figure 6.

Elsewhere in the test site, the nighttime imagery was influenced primarily by farming practices, or the quality of imagery was so poor that little interpretation was possible. The quality of imagery in the 3- to 5.5-micrometer range was too poor to be used.

Verification of Data

Verification of the interpreted map unit designations was performed by comparison to the field soil data collected for this purpose. Mapping accuracies, expressed as the percentage correct, were evaluated for the first 5 of the 6 items that constitute the map unit designation. These items were interpreted from remote-sensing data. Slope designations (item 6), which were taken from USGS topographic maps, were not considered in this analysis.

A good degree of accuracy (average 91 percent) in the interpretation of landforms (item 1) was achieved in all study areas. A varying degree of success was achieved in use of the interpretative modifiers (items 2 to 5) in different study areas. The low degree of success for item 2 (average 37 percent) might be attributed to the lack of familiarity with the Unified Soil Classification System. More success was achieved with item 3 (Kansas classification system); the average accuracies were 83, 87, and 38 percent for the 3 test areas. The low accuracy in one of the areas may be attributed to the fact that this area was characterized by alluvial soils that are highly erratic. A fair-to-good degree of accuracy was achieved in the interpretation of item 4 (average 84 percent) but especially so in the area where the soil mantle was relatively thin (average 96 percent). The detailed comparisons are given in the report by Stallard and Meyers (1).

The significance of the type and the amount of information conveyed to the user cannot necessarily be evaluated by percentage. Although some users may desire 100 percent accuracy, the objectives of the soils investigation must be achieved with a realistic expenditure of time and money. In addition, the type and the amount of information presented on a soils map are limited to the type and the amount of information the interpreter can extract from the photography and imagery. In essence, the soils map should reflect what the user needs and what the interpreter can provide. Soils mapping in Kansas for highway engineering purposes requires 3 items that may be inferred from aerial photography and remote-sensing imagery. They are depth to bedrock, depth to groundwater table, and major changes in soil material types. Generally these factors cannot be determined directly, but inferences and deductions must be made based on surface manifestations and data extracted from imagery. Usually information on these factors will be given as a range of values. Although not precise enough for design purposes, such information provides the location, soils, and design engineers with an excellent insight into the terrain being investigated for a prospective project.

CONCLUSIONS

The following conclusions are based on the visual analysis of the various photography and imagery obtained for this study.

1. Color, small-scale (1:10,000) photography is the best single source of soil information. The low-altitude color (1:2,000) had a scale too large for use in effective soil mapping.

Figure 5. Infrared imagery (Oskaloosa area) (8- to 14-micrometer range, scale = 1:36,000, black = cold, and white = hot).

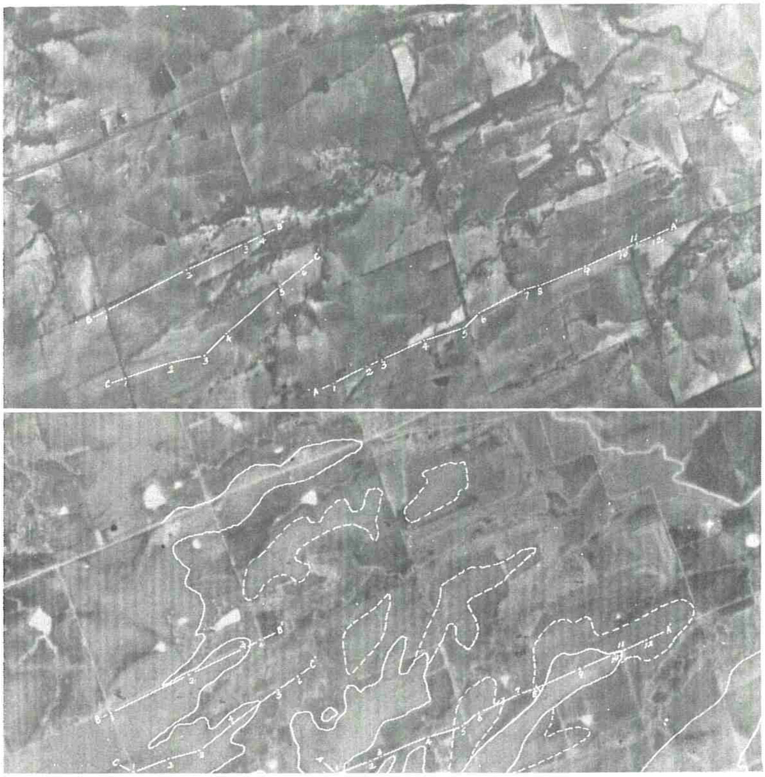
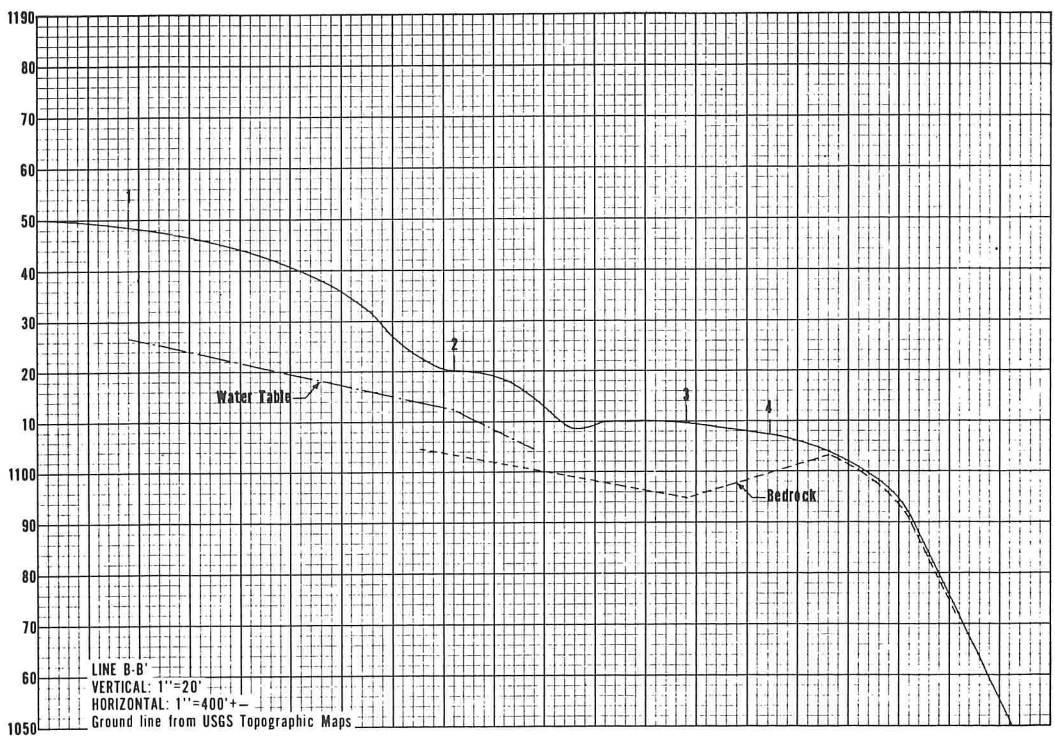


Figure 6. Profile for infrared imagery (Oskaloosa area).



2. Contrast of soils can be enhanced by use of narrow-band photography in the red and infrared portion of the spectrum.

3. Color infrared photography provided information similar to that provided by color photography; additional contrasts revealed vegetation changes. This medium could possibly provide as much information as any single sensing method if proper photographic techniques are used and if the photography were acquired when optimum climatic and environmental conditions prevailed.

4. Day infrared imagery provided information primarily attributable to superficial conditions. Little additional information could be obtained, other than the location of springs and wet areas. Night infrared imagery used in conjunction with the photography was useful in mapping bedrock outcrops and spring areas and in ascertaining relative soil depths, high groundwater levels, and wet areas. Significant delineations were made in areas where uniform ground conditions existed over large portions of the terrain; that is, most of the area was characterized by pastureland, and thermal changes due to marked differences in land use practices did not obliterate the more subdued changes that may have been evident because of different thermal characteristics of soils.

5. The combined use of color aerial photography and infrared imagery (8- to 14-μm range, nighttime, high-altitude) renders the most distinctive evidence for detection, evaluation, and mapping of engineering soil groups.

6. SCS data provide a general knowledge of an area that could serve as a base on which the remote-sensing data could be applied. Modifications and redefinition of engineering soil groups could be accomplished during the analysis of the remote-sensing data.

REFERENCE

1. Stallard, A. H., and Myers, L. D. Soil Identification by Remote Sensing Techniques in Kansas, Part I. State Highway Commission of Kansas, Final Rept., 1972.

ENGINEERING SOIL MAPPING FROM MULTISPECTRAL IMAGERY USING AUTOMATIC CLASSIFICATION TECHNIQUES

Terry R. West, Purdue University

Multispectral imagery collected over southeastern Pennsylvania by Willow Run Laboratories, University of Michigan, was analyzed at the Laboratory for Applications of Remote Sensing using its current capabilities for automatic classification. The project involved the evaluation of imagery in 13 discrete bands of the spectrum as a source of data on engineering soils. Detailed computer classifications of two 4-mile segments of the Pennsylvania flight line, each containing predominantly 1 parent soil material, were obtained. Classification accuracy as measured by training field and test field performance was more than 90 percent. These 2 segments were used as a basis to obtain a computer-implemented map for 12 miles of the flight line.

•IN JUNE 1970, the research project to analyze by digital computer multisensor data collected over various test sites was initiated by the Laboratory for Applications of Remote Sensing (LARS), Purdue University. This research involves using the LARS digital computer and automatic multispectral data analysis techniques for analyzing remote-sensing data and for performing engineering soil mapping. The work done for the Pennsylvania test site is discussed in this paper.

Soil pattern recognition using the LARS approach predates this study. Agricultural soil studies have involved detailed mapping of relatively small areas (about 100 acres) located in the glacial areas of the midwestern corn belt where topographic relief is low. Previous work applying the LARS techniques to engineering soils has been reported by Rib and Miles (3) and by Tanguay and Miles (4) and involved glaciated terrain and bedrock areas. The Pennsylvania flight line, over a region of bedrock-derived residual soils having moderate relief, presented a new challenge to the continually evolving LARS techniques.

DESCRIPTION OF TEST SITE

The test site location in southeastern Pennsylvania was selected by the Pennsylvania Department of Transportation and the Federal Highway Administration because of its accessibility and because of the favorable geologic features of the area. It is approximately 47 miles long. The flight line lies at right angles to the prominent structural trend of the Appalachian Mountain system. This orientation maximizes the number of different rock units intercepted by the flight line. Also, the extensive cultivation in the area maximized the percentage of bare soil present in the spring when the flight was made. The southern end is located in the Piedmont physiographic province, but the flight line soon enters the Valley and Ridge province and ends there about 40 miles to the north.

The geology of the Pennsylvania test area can be described as consisting of simply to complexly folded, steeply dipping sedimentary rock strata cut by several fault systems and igneous intrusions of Triassic age. The sedimentary rocks are primarily sandstone, shale, limestone, and dolomite sequences of Paleozoic age, but they also contain some Triassic sandstone, shale, and conglomerate. Southeastern Pennsylvania has not been glaciated, and the soils consist of residual material formed by surface weathering of the parent bedrock. Local relief in the area ranges from 100 to 500 ft and the elevation from 350 to 1,000 ft above sea level. Annual precipitation is approximately 41 in./year, and dense forests develop in areas not under active cultivation.

Because of the complex structure of the sedimentary rocks, portions of the flight line were selected that contained predominantly 1 parent bedrock material. These specific "pure soil" areas were selected with the intention that analysis would first be accomplished for these and subsequently extended to the more diverse areas between them. Table 1 gives information on the pure soil areas.

REMOTE-SENSING DATA COLLECTED

The multispectral imagery used in this study was collected by the Willow Run Laboratories, University of Michigan, under a separate contract with the Federal Highway Administration. The data were collected with a multispectral optical-mechanical scanner mounted in a DC-3 aircraft and were recorded on magnetic tape. Duplicate copies of the tape were furnished to LARS for this study.

The specific multispectral bands recorded on aircraft storage tapes vary according to the needs of the researcher. In this study, a total of 15 channels of data were obtained, 13 in the visible and reflective infrared portion of the spectrum (between 0.4 and 2.6 μm) and 2 in the thermal infrared (4.5 to 5.5 μm and 8.0 to 14.0 μm).

The flight line was flown May 15, 1969, at 3,000 ft above the average terrain elevation. The data were recorded on 2 tapes: tape 1 for the southern half and tape 2 for the northern half of the flight line.

Each segment was flown during both the day and the night. For the daytime flights, visible, reflective infrared, and thermal infrared data were obtained. At night, measurements were limited to the thermal infrared.

In addition to the aircraft data tapes, other information made available to LARS included black-and-white 9- by 9-in. aerial photographs plus an aerial photomosaic for the flight line; topographic maps for the area and agricultural soil maps for Berks and Lancaster Counties; cathode-ray tube imagery of 3 wavelength bands (one each in the visible, reflective infrared, and thermal infrared); 70-mm color photography; and 9- by 9-in. color and color infrared photography.

LARS TECHNIQUES FOR MULTISPECTRAL DATA ANALYSIS

This section is intended to familiarize the reader with the current LARS analysis techniques for multispectral remote-sensing data. Because of space limitations, this discussion has been abbreviated. Detailed descriptions of the techniques are given by Tanguay and Miles (4), Hoffer and Goodrick (1), and West (5).

Remote sensing involves the identification and classification of surfaces through analysis of data from sensing devices not in direct contact with those surfaces. At LARS these data are analyzed on a digital computer using multivariate-pattern recognition techniques. Currently, imagery collected in the visible through thermal infrared portions of the spectrum are included in pattern recognition studies.

The data collected during the flight are in an analog format. By means of the LARS data-handling system, these analog data tapes are converted to digital form. Each analog scan is sampled, normally at a sampling rate that yields 220 data points for an 80-deg field of view across the flight line. For later reference, each digitized data point is assigned a unique address in a 2-dimensional coordinate system based on scan line numbers (line numbers) and samples within the line (column numbers).

A final preprocessing function, data overlaying, must precede analysis of imagery from multiple-aperture scanners. In 1969, when these data were obtained, the University of Michigan scanner system collected data from 3 apertures (visible, reflective infrared, and thermal infrared). In such cases, data overlaying is performed to align the data so that pattern recognition can be based on all channels. Checkpoints, such as field corners and highway intersections, are located on gray scale printouts (described below) for channels obtained through different apertures. After an array of such checkpoints is established throughout the flight line, the computer aligns these points and forces the data between them to line up as well as possible. Typically, the discrepancy remaining after data overlaying is at most 2 or 3 resolution elements. A resolution element or remote-sensing unit (RSU) is the area on the ground represented by a single reflectance symbol or letter on a gray scale printout. At the 3,000-ft altitude of the Pennsylvania flight, this represents about a 20-ft square on the ground.

The computer programs used at LARS to analyze multispectral scanner data are shown in Figure 1. Indicated are the sequential and alternative steps involved in the analysis procedures.

Typically the initial step in the analysis is to obtain gray scale printouts of the data for several channels ($PIC, Fig. 1). Gray scale printouts are digital displays of the spectral response of the terrain but limited to 1 band or channel of the scanner data per display. They resemble low resolution photographs.

The researcher locates areas of known materials on the gray scale printouts and records their addresses. This information, referred to as ground truth, is used to train the computer to recognize similar material. In agricultural studies, this training information may consist of fields containing corn, wheat, oats, or soybeans; in forestry studies, it may consist of conifers and deciduous trees or individual tree species; and in geology and highway engineering, it may consist of specific bedrock and soil types. Although some of the ground truth areas are used to train the computer to recognize the classes of interest, the remaining areas are reserved for testing the accuracy of the computer classification after it is completed.

After January 1, 1971, an alternative to the use of gray scale printouts became available at LARS. This tool, known as the digital display unit (FIELDSEL) provides a television-like image of the scanner data; each digital value is represented by a different brightness level. This yields an image on the screen having greater detail than is possible with gray scale symbols on computer paper. Images for each channel can be displayed, fields of interest can be outlined on the screen by a light pen, and their addresses can be automatically punched on cards.

Another method for obtaining training field sites is sometimes used in conjunction with the procedure given above. This involves the use of the clustering program NSCLAS (nonsupervised classifier, Fig. 1). This relatively new technique divides the scanner data into groups or clusters based on similarity of spectral response within clusters. Typically 4 to 6 channels of imagery are analyzed simultaneously, and the program is requested to obtain 10 clusters. A computer display of the results is printed for each area analyzed in this way, and the researcher can observe the patterns of spectrally differentiable material occurring in the data. The training fields may then be selected. The resulting clusters may not in fact be spectrally distinct, but the researcher must decide this to his own satisfaction based on separability information for the clusters that are printed by the program. He then has the option of repeating the analysis and using a different number of clusters to increase their separability. An important point is that this method of selecting training fields takes into account the multispectral response data as well as the ground truth information.

In the clustering approach, the actual differences in spectral response are displayed, but a major problem exists in determining what each of the clusters represents. They may be vegetation types, water bodies, man-made features, or tonal aspects of bare soil and rock. Aerial photography is helpful in affixing names to the patterns observed. Despite this difficulty, clustering is a powerful tool in obtaining workable training fields. The clustering technique, which was under development during the analysis phase of the work reported here, was not applied to these data. It was subsequently used for detailed soil mapping of the Pennsylvania data (2) and in a brief study in Indiana (6).

The next step in the analysis is to obtain histograms for each class of material identified in the training fields ($STAT). An example of classes for a geologic study area might be alluvium, limestone soil, shale soil, trees, mixed crops, and water. The histograms for each class show the distribution of reflectance intensity for each spectral channel.

Unimodal or single-peaked distributions in the histograms for a class suggest that the proposed class is spectrally an individual group. Bimodal or trimodal distributions must be subdivided manually into unimodal classes by the researcher; histograms for individual fields can be obtained to help in locating the multimodal contribution within a class.

The next operation involves the application of a divergence (statistical separability) analysis (known as $DIVERG) to determine the best channels to use for classification. Only the best 4 to 6 channels are used for classification in order to save computer

time; in general, the accuracy of classification is not meaningfully increased when more channels are added. In addition to indicating the preferred channels, the divergence analysis indicates the separability of the designated classes. If separability between significant materials is poor, some of the preceding steps may be repeated in an attempt to improve this separability and hence classification accuracy.

Next, the training field statistics are used to classify the designated portion of the flight line ($CLASSIFY). The computer classifies each data point (RSU) based on a maximum likelihood criterion. On request, the computer calculates how accurately it classified the areas used for training by comparing the classification of each point in the training fields with the initial ground truth designation. A high level of agreement means there is minimal confusion within the training field statistics of the various materials and that the classes are being separated properly.

The final steps are to print out a computer classification display map for the whole area ($DISPLAY) and to determine how well the test fields were classified. The test fields are those areas of known material from ground truth studies that were not previously used for training purposes. If test fields and training fields show a high degree of accuracy and the test fields are representative of the entire area, the classification is a good one. If the accuracy is low, some reworking of the classes should be done. The researcher may also have to conclude that the classes involved are not spectrally separable.

RESULTS OF STUDY FOR THE BLUE BALL AND REAMSTOWN-DENVER AREAS

Initial work during the contract period was performed on data from the Blue Ball area. Prior to this, a brief study had been made on a 12-mile section immediately to the south of Blue Ball near Welsh Mountain, a prominent quartzite, tree-covered ridge. This preliminary study, set up to determine the potential of the LARS system for engineering soils, was most rewarding in that it suggested an improved approach for analyzing the total flight line.

The Welsh Mountain study was complicated by the diverse geologic and topographic nature of the area. It is a complex region of the Piedmont province displaying as much as 500 ft of relief due to differential erosion of rocks with contrasting resistance to weathering. Soils derived from limestone, schist, quartzite, and a mixture of these, talus or colluvium, mantle the area.

Because of these complexities, very accurate ground truth information was necessary for training the computer to distinguish between the various materials. Such detailed information, as later determined, was unavailable. In areas of high relief composed of resistant rocks, it is common for pieces of durable rock to be moved downslope by gravity and to accumulate as a mixture of materials at a lower level. This colluvium displays some of the spectral characteristics of all the parent materials involved. As the extent of colluvium exposed at the surface was not known, it was omitted from the training samples.

In the computer-generated classification of the Welsh Mountain area, vegetation and water were accurately delineated; however, classification of the soil types did not agree well with the known geological conditions of the area for the reasons previously stated. Because of these inaccuracies in this complex area, it was decided to concentrate on pure soil areas where the complications are minimized. This supplied the impetus to use the pure soils area approach for the Pennsylvania flight line.

Blue Ball Area

The first pure soil area studied, located near Blue Ball, is 3.6 miles long and approximately 5,000 ft wide. It lies near the southern end of the flight line in Lancaster County and is designated as pure soil areas 1 and 2 (Table 1). The following discussion, a step-by-step description of the manner in which the final Blue Ball classification was accomplished, is presented as an example of the details involved in obtaining an accurate classification.

This flight line segment consists primarily of residual limestone soil with some river alluvium located along a small creek. It was eventually determined that 3 conditions exist in this residual limestone soil: eroded areas where the subsoil is exposed, noneroded areas, and places where local alluvium derived from erosion has accumulated. These combined conditions (which can be observed on the color photos and to a lesser extent on the gray scale printouts of the multispectral scanner data) made analysis of the Blue Ball site difficult. Visible and reflective infrared channels were included in the analysis.

The first classification of the Blue Ball area was based on 10 fields outlined on air photos that were suggested for training by the FHWA photo interpreter. Training fields in the river alluvium along the creek, which had not been represented previously, were added, and the Lancaster County soils map provided ground truth information. Early results suggested that more spectral classes of limestone soil were present than were represented by the training fields. In the subsequent refinement, many additional limestone training fields were added from the entire area in an attempt to represent all possibilities. Test fields were selected at the same time.

For this next classification, results still indicated difficulty in differentiating river alluvium, local alluvium, and limestone soil. Field checks were made by staff from the Department of Agronomy, Pennsylvania State University, at LARS' request. This field study indicated that the agricultural soil map was not entirely accurate, and this new information was used to discard some training fields, regroup others, and add new ones, specifically categories for eroded limestone and local alluvial accumulation. A series of classifications was made, fields that proved troublesome were deleted, and several new factors were added such as training fields from a limestone quarry. Approximately 75 limestone training fields were used in the final classification. The training fields were evaluated after the classification was completed, and these results are given in Table 2. The overall performance was 97.7 percent correct, and the average performance by class was 97.8 percent correct.

After the classification was made, 58 test fields in the limestone soil were used to determine the accuracy of the classification. For these fields, which comprised 3,340 data points or RSU's, an accuracy of 90.6 percent was obtained.

In the process of improving the classification, several class divergence analyses were made. As a result, the 75 limestone fields were eventually combined into 14 separable classes. Several of the final classes were relatively similar but collectively were sufficiently different so that, if combined, they would yield a combined class too broad for useful classification. Hence, the 14 classes were maintained as separate entities.

The divergence analysis identified the 4 best channels for classification. As vegetation types are not an important aspect in this study, the vegetation classes were omitted in the divergence analysis. This meant that only separability between different soil groups would be a factor in determining which channels to use. Maximum significance was assigned to distinguishing between limestone, local alluvium, river alluvium, and eroded soil. This resulted in the selection of channels 2, 7, 12, and 13 as the 4 best channels for classification (0.44 to 0.46, 0.58 to 0.62, 1.00 to 1.40, and 2.00 to 2.60 μm respectively).

A third divergence analysis, identical to the preceding except for the deletion of channels 12 and 13, was then performed in order to determine whether channels 12 and 13 contributed enough toward class separability to warrant their inclusion. Because these channels are obtained from a scanner aperture different from channels 1 through 11, these upper channels are significantly involved in the overlay problem, with the misalignment ranging up to 3 resolution units despite overlay adjustments. Results indicated a marked reduction in separability of some key classes when channels 12 and 13 were omitted, signifying that they were needed for proper separation. Thus, channels 2, 7, 12, and 13 appeared best for the classification.

Reamstown-Denver Area

The Reamstown-Denver area, designated as pure soil area 4 (Table 1), was the second pure-soil area studied. The Reamstown-Denver pure soil study area is about

$4\frac{1}{2}$ miles long and 5,000 ft wide. This study area contains several soils that are derived from very different parent materials (bedrock). Much of the area is underlain by Ordovician age limestone, which yields a limestone soil similar to that found in the Blue Ball area. The limestone soil conditions in Reamstown-Denver are simpler, however, because the severely eroded areas are absent.

Present also in the Reamstown-Denver area are soils derived from dark-gray Ordovician age shales and soils derived from Triassic age red-colored shales, sandstones, and conglomerates. In addition, river alluvium and river terrace materials are present. The water and vegetation classes are similar to those in the Blue Ball area.

Training samples were selected from the different soil types in the Reamstown-Denver site, combined into classes, and used to classify the existing surface materials. Twenty-three classes consisting of 76 fields were used. The same channels used in the Blue Ball classification, 2, 7, 12, and 13 (0.44 to 0.46, 0.58 to 0.62, 1.00 to 1.40, and 2.00 to 2.60 μm respectively), were used. Several classifications were required because adjustments for the troublesome training fields were needed before an acceptable classification was obtained for the area. The training fields were evaluated for the Reamstown-Denver classification, and these results are given in detail in Table 3. The overall performance was 98.2 percent accurate, and the average performance by class was 97.8 percent.

After the completion of the Reamstown-Denver classification, the training classes for both the Blue Ball and the Reamstown-Denver areas were combined to yield 43 classes and approximately 150 training fields. The area from Blue Ball continuously through to Denver, a distance of 11.6 miles, was classified by the use of the resulting statistics. Included in this 11.6-mile segment is pure soil area 3, Independence School. This area of Triassic age shale, sandstone, and conglomerate was mapped in this manner. The results obtained for area 3 are realistic and quite good considering that no training samples were taken directly from that area.

For the 11.6-mile segment, the training field performance averaged 95.6 percent correct. This high level is somewhat misleading in regard to the actual accuracy, for no new test fields were evaluated. A problem that occurs is the confusion between shale-derived soils in Reamstown-Denver and the limestone soils in Blue Ball. This misclassification is related to the presence of transitional local alluvium and limestone soil. Despite these difficulties, the extended classification is a significant step toward the objective of using the LARS computer techniques to map engineering soils for large areas of a flight line.

SUMMARY AND FUTURE WORK

Results from the 2 pure soil areas, Blue Ball and Reamstown-Denver, indicate that engineering soil materials can be mapped at the Pennsylvania test site in considerable detail when adequate ground truth is available. Vegetation, water, roads, rooftops, and quarries can also be discerned. Vast amounts of detail are available from multispectral analyses, much of which is due directly to soil properties and conditions. For example, locations of wet soil and areas where soil cover over bedrock is thin may be outlined.

Classification of the 11.6-mile segment from Blue Ball to Reamstown-Denver marks a step toward classifying longer portions of a flight line by extending classification from smaller segments. This could possibly be extended to achieve a classification of the southern half of the flight line if additional training fields from the unrepresented soil types were obtained. The achievement of a combined flight-line map was an objective of the study, and the pure soils area concept was initiated in hopes of accomplishing it.

Two problems arise when mapping is done for a large area that contains numerous spectral classes of material. First, there is a physical limit on the number of classes that can be processed by the computer programs; the number is primarily a function of computer memory limitations. The current limit at LARS is 60 classes, and the 11.6-mile classification with 43 classes approached this limit. Second, accurate classification becomes more difficult when numerous material types are considered. Simply stated, the probability of having overlapping spectral characteristics of materials is increased when greater numbers of similar materials are included.

Table 1. Pure soil areas.

Pure Soil Area	Designation	Predominant Parent Materials	Geologic Age
1	Blue Ball	Limestone	Cambrian
2	Blue Ball	Limestone	Cambrian
3	Independence School	Sandstone and shale	Triassic
4	Reamstown to Denver	Limestone	Ordovician
5	Union House	Sandstone and shale	Triassic
6	Sheridan	Limestone	Ordovician
7	Mt. Aetna	Sandstone and shale	Ordovician
8	Bethel	Sandstone and shale	Ordovician

Figure 1. Computer programs for classification of multispectral scanner data.

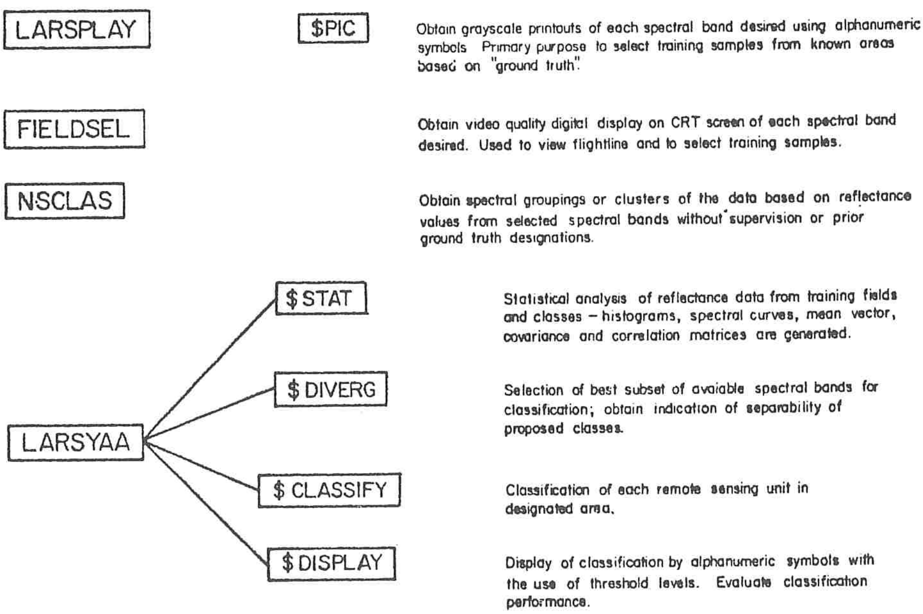


Table 2. Training field performance—Blue Ball.

Group	Number of Samples	Correct (percent)	Samples Classified: Veg	Lime	Alv	Loclv	Rival	Erod	Threshold[a]
Vegetation	519	100.0	519	0	0	0	0	0	0
Limestone soil	3,586	97.4	16	3,491	3	62	1	0	13
Alluvium	43	97.7	0	0	42	0	1	0	0
Local alluvium	86	96.5	0	3	0	83	0	0	0
River alluvium	149	98.7	0	1	1	0	147	0	0
Eroded limestone soil	32	96.9	1	0	0	0	0	31	0
Total	4,415		536	3,495	46	145	149	31	13

[a]No classification made (data very unlike any training class).

Table 3. Training field performance—Reamstown-Denver.

Group	Number of Samples	Correct (percent)	Samples Classified: Qua	Tpk	Roof	Water	Alv	Ter	Lime	Shale	Tri
Quarry	142	97.2	138	1	3	0	0	0	0	0	0
Turnpike	27	100.0	0	27	0	0	0	0	0	0	0
Roof	53	98.1	0	0	52	0	0	0	0	1	0
Water	104	100.0	0	0	0	104	0	0	0	0	0
Alluvium	70	92.9	0	0	0	0	65	0	0	1	4
Terrace	194	98.5	0	0	0	0	2	191	1	0	0
Duffield (limestone soil)	534	99.3	0	0	0	0	1	1	530	0	2
Berks (shale soil)	224	99.6	0	0	1	0	0	0	0	223	0
Penn (from Triassic red beds)	165	94.5	0	0	0	0	5	0	4	0	156
Total	1,513		138	28	56	104	73	192	535	225	162

A new approach now being explored is to include in the first classification attempt only the soil types that are anticipated in the extended area. For example, soils derived from metamorphic rocks such as schist, quartzite, and slate would not be included as training classes for an area derived from sedimentary bedrock. An initial subdivision into broad soil groups along the flight line would be made first. The cluster analysis would be applied to delineate these general groups and to remove the human bias in training field designation. Detailed analysis of each general group using typical classes of material for that area would follow.

ACKNOWLEDGMENTS

This research project was sponsored by the Federal Highway Administration with some support by the National Aeronautics and Space Administration, the primary funding agency of the LARS facility. The ongoing project is a portion of the Cooperative Remote-Sensing Research Program of FHWA monitored by H. T. Rib, whose efforts in coordinating the research are hereby acknowledged. Special thanks are afforded to R. L. Cunningham and H. L. Mathews, Department of Agronomy, Pennsylvania State University, who aided in the field identification of surface materials, and to P. H. Swain, of LARS, who critically reviewed the manuscript.

REFERENCES

1. Hoffer, R. M., and Goodrick, F. E. Geographic Considerations in Automatic Cover Type Identification. Proc., Indiana Academy of Science, Vol. 80, 1971.
2. Mathews, H. L., Cunningham, R. L., West, T. R., and Cipra, J. E. Application of Multispectral Remote Sensing to Soil Survey Research in Southeastern Pennsylvania. Paper presented at American Society of Agronomy, New York, 1971.
3. Rib, H. T., and Miles, R. D. Multisensor Analysis for Soils Mapping. HRB Spec. Rept. 102, 1968, pp. 22-37.
4. Tanguay, M. G., and Miles, R. D. Multispectral Data Interpretation for Engineering Soils Mapping. Highway Research Record 319, 1970, pp. 58-77.
5. West, T. R. Applications of Remote Sensing to Highway Locations. Proc., 21st Highway Geology Symposium, Lawrence, Kan., 1970.
6. West, T. R. Engineering Soils Mapping in Indiana by Computer From Remote Sensing Data. Proc., Indiana Academy of Science, Vol. 81, 1972.

AIRBORNE MICROWAVE RADIOMETER SURVEY TO DETECT SUBSURFACE VOIDS

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Airborne radiometric measurements were obtained over an area in Kansas City, Kansas, during March 1970. The purpose of the measurements was to determine whether the radiometric temperature of the earth's surface could be used to detect and possibly map subsurface voids beneath thick soil cover so that potential highway foundation problem areas could be located. The microwave survey showed significant radiometric relative low-temperature anomalies corresponding to the presence of subterranean voids. The conclusion is, therefore, drawn that there is a high correlation between subsurface voids and radiometric low temperature.

•AN EXPERIMENT to determine the possibility of detecting subsurface voids by the use of an airborne microwave radiometer was planned for March 1970. The airborne data were collected by Remote Sensing, Inc., under contract to the State Highway Commission of Kansas and in cooperation with the Federal Highway Administration. The data were reduced and analyzed by Resources Technology Corporation under contract to the Federal Highway Administration and in cooperation with the State Highway Commission of Kansas.

The area surveyed is a 2,000-ft square approximately ¼ mile northeast of the intersection of Gibbs Road and 42nd Street, Kansas City, Kansas. This area was partially mined in the past, and subsurface voids were left. Figure 1 shows the area surveyed; the depths to the underground cave ceilings are shown in the form of isopachs, previously determined by underground mapping and auger core holes. The experimental airborne microwave survey was to evaluate the potential of remote microwave radiometry in detecting and mapping subsurface voids by searching for correlations between survey measurements and the known cave in Figure 1.

MICROWAVE THEORY AND EMPIRICAL KNOWLEDGE

Electromagnetic theory shows that all objects above absolute zero emit radiation produced by the oscillations of charged atomic and molecular particles. In the microwave portion of the spectrum, generally agreed to lie at frequencies between 1 and 100 GHz, the Rayleigh-Jeans approximation to Planck's radiation law (valid to within 1 percent) expresses the microwave radiation of a body as equal to its emissivity (at the relevant frequency) times its thermometric temperature. The emissivity of an area of the ground is an extremely complex function of both electrical and geometrical properties. These properties are in turn representative of soil type, soil moisture content, vegetation coverage, and surface roughness. Present knowledge of the exact mechanisms that result in ground radiation temperature is not sufficient to predict microwave temperatures, given all ground characteristics, except in certain ideal conditions.

However, experiments and theory have shown that soil water content is very influential in affecting ground microwave temperature. The more moisture a soil contains, the cooler is its temperature; thus, any differences in microwave temperature because of underground voids will be related to the perturbation of the groundwater drainage system caused by the void. Moreover, the presence or absence of water in the cave itself will tend to lower or raise the radiometric temperature measured. The exact mechanisms that can make subsurface voids appear warmer or cooler radiometrically are at present not fully established.

Figure 1. Isopach of cave ceiling.

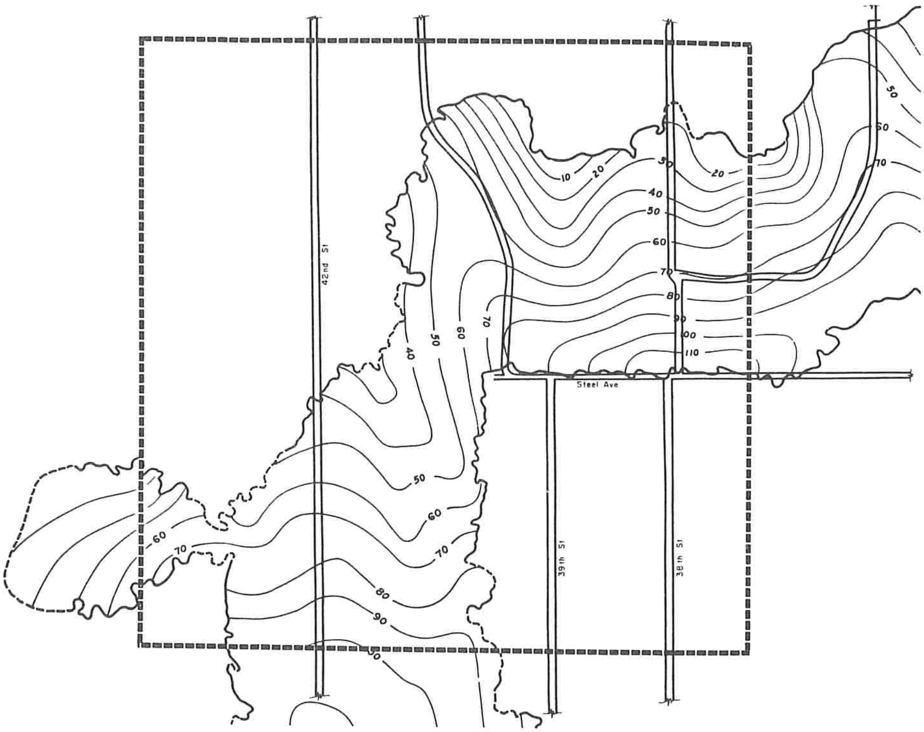


Figure 2. Ground moisture 10 in. below surface.

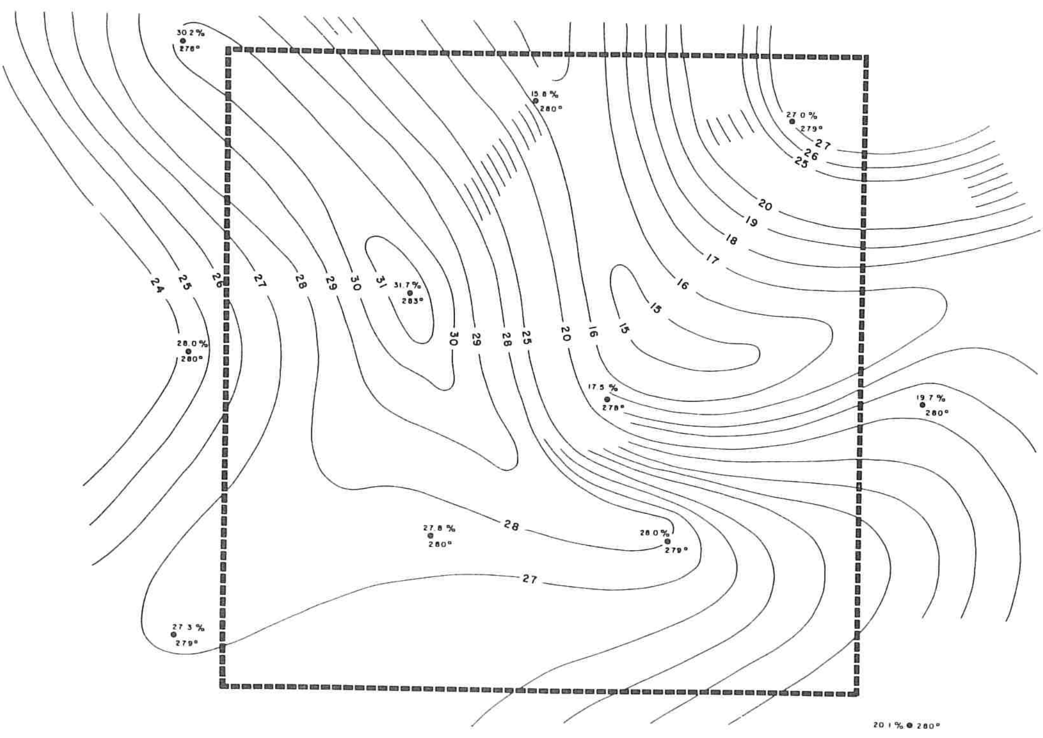


Figure 3. Microwave profile of line 1.

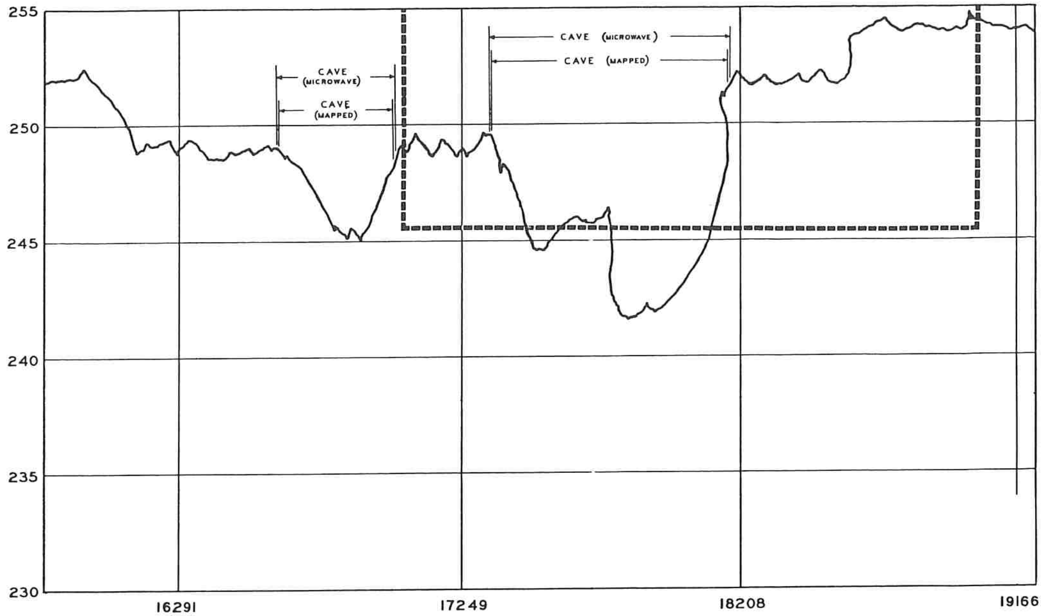


Figure 4. Microwave temperature.

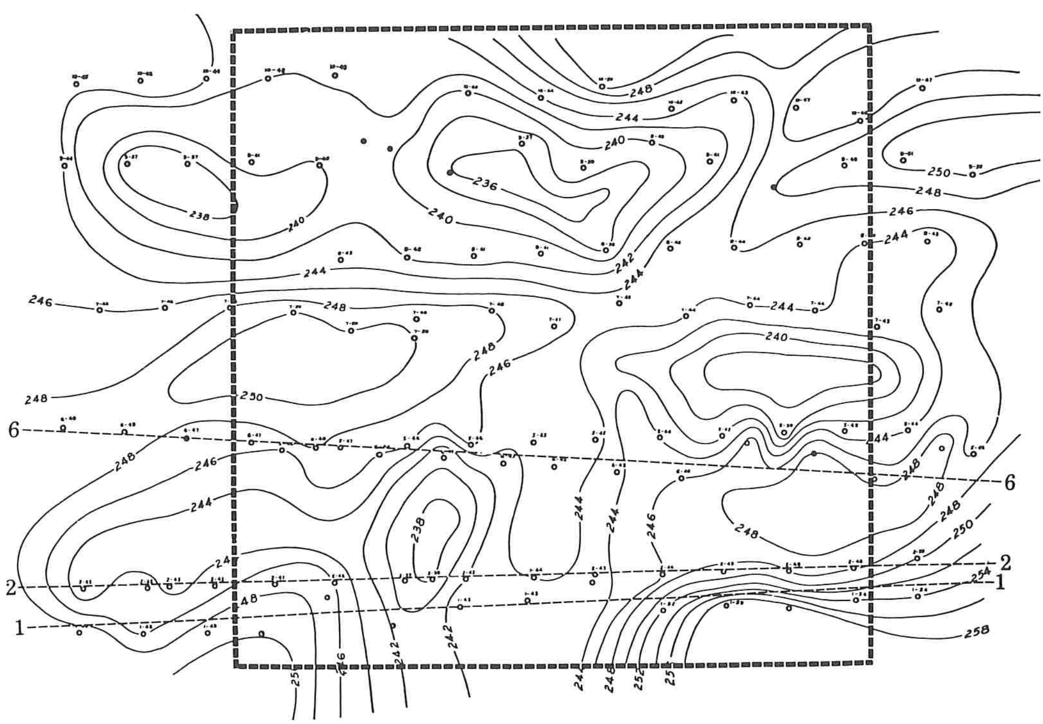


Figure 5. Topographic map of site.

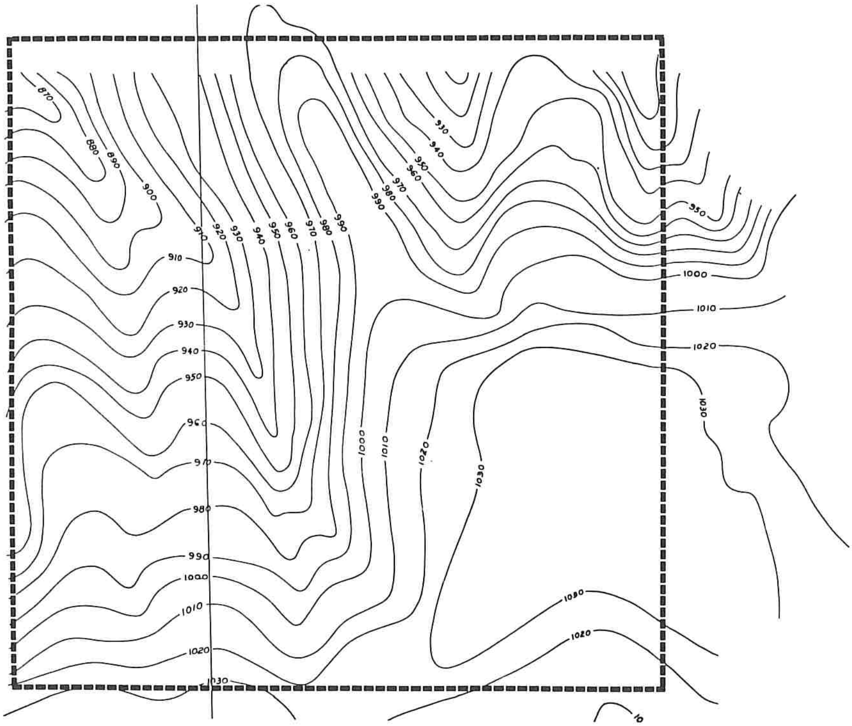
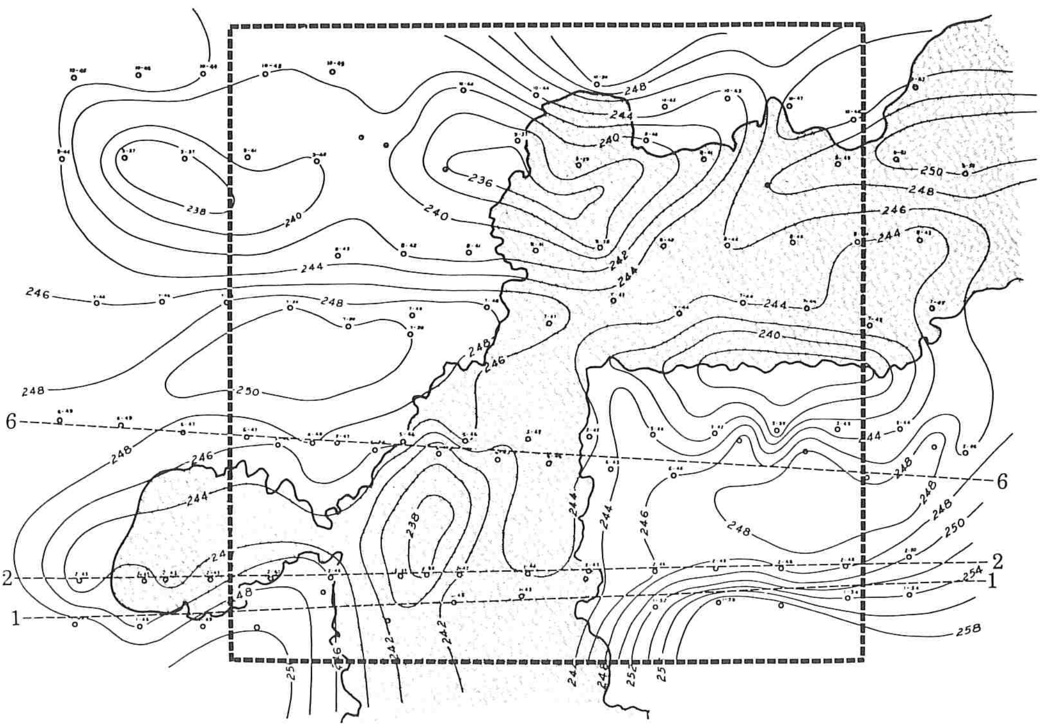


Figure 6. Microwave temperature and outline of cave.



An experiment by Kennedy (1) indicated that cold microwave anomalies may be associated with buried karst features. The experiment was conducted in an area similar geologically to the area surveyed in the present study. Measurements of microwave temperature were made at ground levels in the 1968 experiment and were made in the air in the present survey. The results of the ground measurement encouraged the aerial survey because of the rapid synoptic coverage aerial surveys provide.

DESCRIPTION OF EXPERIMENT

Ground truth in the form of surface moisture content and ground thermometric temperatures was sampled over the area. Figure 2 shows a summary of moisture content by means of contours and contains representative thermometric temperature measurements. Some ground radiometer data (8- to 14-μm range) were also collected.

Daytime and nighttime missions were flown at 15,000 ft above the terrain in a grid pattern. In the daytime, 2 east-west and 2 north-south flights were made. In the night mission, 11 east-west lines and 11 north-south lines at 200-ft separations were flown. The flight lines were controlled by the use of amber rotating beacons on the ground. The lines were flown from midnight until about 5:00 a.m., when thermal equilibrium of the environment should be greatest. The data gathered were digital recordings of the aircraft roll, pitch, and heading angles versus time on a computer-compatible, ½-in., 7-track digital tape; continuous data of brightness temperatures versus time on a 1-in., 14-track analog tape; and film strips from an airborne infrared scanner. The radiometer used was vertically polarized with a center frequency of 13.3 GHz.

The temperature data were digitized and processed by computer and resulted in profiles of brightness temperature versus ground-beam axis intercepts. Figure 3 shows an example of the resultant temperature profiles developed for the survey lines. Figure 4 shows a radiometric isotherm map of the area prepared from the temperature profiles.

Comparisons between radiometric temperature measurements made from an aircraft and existing landform voids are demonstrated by the profile shown in Figure 3. This graph reveals a striking correlation between the actual cave widths and the recorded cool anomalies. However, these profiles are not representative of the entire set, from which the contours shown in Figure 4 were drawn, but rather are drawn from the subset that showed the best correlations. Other profiles showed less correlation.

A visual comparison of the radiometric temperature contour map (Fig. 4) and a topographic map of the area (Fig. 5) does not appear to show any significant correlation, nor can any substantial correlation between radiometric temperature and soil moisture content (Fig. 2) be shown. This lack of correlation may lend credence to the assumption that one of the factors affecting microwave temperature is the presence or absence of subsurface voids.

The radiometric isotherms show definite closures of cold anomalies. Superimposing the limits of the cave on the isotherm map, as shown in Figure 6, reveals that 3 of the anomalies occur over the known void. The fourth anomaly, detected in the northwest quarter of the area, does not appear to be connected to the known cave.

It is concluded that an airborne radiometer may have some potential in detecting voids. Further microwave field surveys over areas with known voids are now being conducted to more positively identify the cause of the anomalies.

REFERENCE

1. Kennedy, J. M. A Microwave Radiometric Study of Buried Karst Topography. Geological Soc. of America Bull., Vol. 79, No. 6, 1968, pp. 735-742.

MULTISPECTRAL REMOTE SENSING OF SOIL AREAS: A KANSAS STUDY

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Multispectral remote-sensor data, coupled with computer processing techniques, provide the capability to automatically delineate surface soil distributions on the basis of spectral properties. An airborne line scanner was used to collect synoptic terrain information in 10 synchronous spectral bands spanning the visible and near-infrared radiation range. The fact that scene data are recorded directly onto computer-compatible magnetic tape allows the use of sophisticated analog and digital processing techniques for terrain analysis and automatic extraction of scene elements. Results of recognition processing of multispectral data collected over a Kansas test site demonstrate that limited surface soil mapping is feasible by this technique. Fluvial soils of varying texture were accurately delineated on the floodplains of the Kansas River and on a small tributary of the Kansas River. Recognition of upland clay soils derived from different parent materials was less successful. This upland recognition may have been adversely affected by small training set size, heterogeneous soils, and slope-illumination variations. Recommendations for continuing research include the study of soil reflectance phenomena, further development of processing techniques, and collection of multispectral data under optimal conditions.

•DESCRIBED in this report are the results of an intensive study into the use of multispectral data for automatically discriminating soils in a highway test area in northeastern Kansas. The study was carried out by the University of Michigan's Willow Run Laboratories under the sponsorship of the Federal Highway Administration in cooperation with the State Highway Commission of Kansas.

REMOTE-SENSOR DATA

Multispectral scanner data used in this study were collected at about 3:00 p.m. on March 4, 1970. The data were recorded at 3,000 ft above the terrain (approximately 4,000 ft above mean sea level). Fifteen spectral bands in the 0.40- to 13.5-μm wavelength range were recorded by 2 double-ended line scanners. These data were recorded directly onto computer-compatible magnetic tape.

Ten of the 15 spectral bands spanning the 0.40- to 0.90-μm range were used for this study (Table 1). These 10 bands were recorded synchronously. The other 5 bands in the 1.0- through 13.5-μm range were not recorded synchronously with the 10 bands and were thus not processed for use in the analysis.

In addition, 70-mm color (Kodak 8442) and color infrared (Kodak 8443) film were exposed with 60 and 20 percent overlap respectively.

KANSAS STUDY SITE

Multispectral data were collected over an area midway between Topeka and Lawrence, Kansas (site 5, described by Stallard in a paper in this Record). In the portion of the test area investigated in this study—the first 15 of the 27-mile test strip—3 major soil parent materials are found: residual limestones and shales, glacial drift, and waterlaid (fluvial) sediments. As one would expect, the soils derived from these parent materials vary considerably in their physical properties. The soils derived from fluvial materials

range in surface texture from silt to clay and in plastic indexes from 5 to 20. The upland residual- and drift-derived soils are mostly clays having plastic indexes from 20 to 50 (1).

The soils are also characterized by their reflectance (color) differences (Figs. 1, 2, 3, and 4). In order of most reflective (lightest) to least reflective (darkest), the soils rank as follows: fluvial silts, upland clays derived from glacial drift, fluvial silty loams, upland clays derived from residual rocks, and fluvial clays (2). The fluvial silty loams were very similar in reflectance to upland clay soils derived from residual rocks. As with most soils, the reflectance of each sample increased monotonically with increasing wavelength. Thus, the greatest reflectance differences between these soils, for the 0.4- to 1.0-μm spectral range, occurred in the near-infrared wavelengths.

SOIL SIGNATURES

Computer-implemented processing techniques employed in this study make use of the surface spectral differences of the soil units recorded by the scanner. The differences are determined by the direct extraction of spectral "signatures" from the data, one signature for each class of interest. The signatures are obtained by locating a known sample area of each soil on an image display of the entire test area. Each sample area is known as a "training set" and is defined either by its image coordinates (digital display) or by electronic gates (CRT display). Only spectral information from the sample areas is then made available to the computer. The computer subsequently determines the mean and the variation of the electronic signals for each training set. Within each training set the spectral reflectance is likely to vary within the limits that define that soil; therefore, the spectral signatures consist of mean values and standard deviations for each channel. The means and standard deviations of all channels constitute the statistical spectral signature for the soil represented by that training set.

Six of the soil spectral signatures used in this study are shown in Figure 5. These are based on training set areas selected with the help of the State Highway Commission of Kansas.

RECOGNITION PROCESSING

Once the statistical signatures have been established, data processing procedures are straightforward. With the spectral signatures of the soil classes in its memory, the computer simply "reads" through the entire data set (all of the multispectral data recorded from the test site) and indicates the location of data "similar" to any one of the signatures. For the computer, similarity is defined by a mathematical decision rule. A number of decision rules are possible, and some are potentially more powerful than others.

The decision rule used for this processing was the "likelihood ratio." In likelihood-ratio processing, each resolution element of the data is classified as "target" or "not target" by noting whether the likelihood ratio L is greater than or less than some threshold value T. In simple form the likelihood ratio is

$$L = \frac{P_A(T)P(T/S)}{\Sigma_n P_A(B_n)P(B_n/S)} \quad \begin{array}{l} > T = \text{target} \\ \leq T = \text{no target} \end{array}$$

where

$P_A(T)$ = a priori target probability;
$P(T/S)$ = probability of target, given a data sample;
$P_A(B_n)$ = a priori probability of backgrounds n; and
$P(B_n/S)$ = probability of background n, given a data sample.

The result of this yes-no type of decision rule is a computer "recognition map." This map is an image display wherein all areas recognized as being similar to a given signature are displayed as a particular symbol or color. Areas of the test site unlike any of the signatures are left blank. Thus, only materials of interest are displayed on the recognition map.

Table 1. Band pass, spectral color, and rank of optimal spectrometer channels.

Spectrometer Channel	50 Percent Peak-Power Band Pass (μm)	Spectral Color	Rank of Optimum Channels
1	0.412 to 0.427	Violet	3
2	0.451 to 0.465	Dark blue	6
3	0.481 to 0.501	Blue	8
4	0.501 to 0.521	Blue-green	4
5	0.521 to 0.548	Green	1 (best)
6	0.548 to 0.579	Yellow	10 (worst)
7	0.579 to 0.623	Orange	7
8	0.623 to 0.674	Red	5
9	0.674 to 0.744	Dark red	9
10	0.744 to 0.852	Near infrared	2

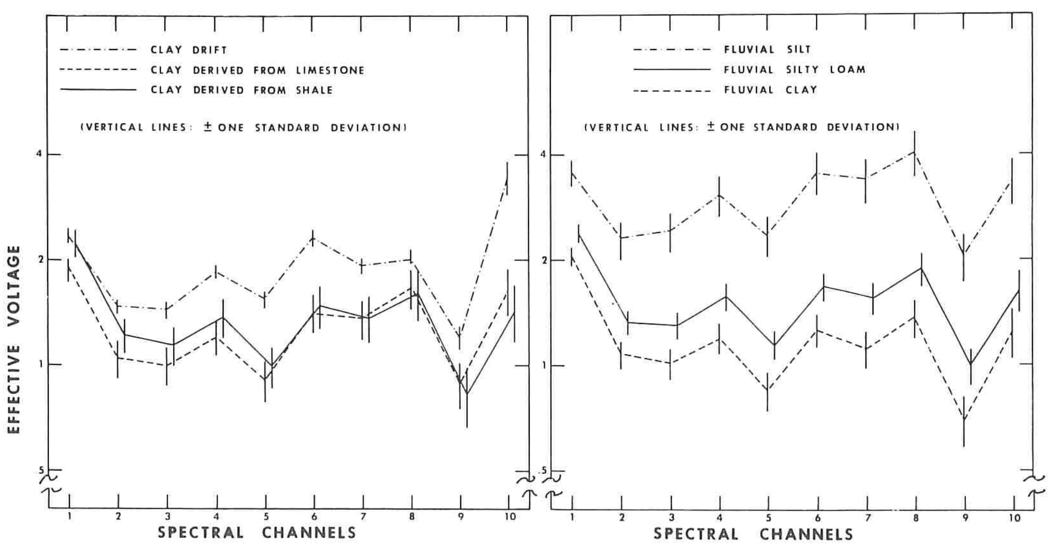
Figure 1. Fluvial silt with dark clay windows.

Figure 2. Shale-derived upland clay loam with drift soil in background.

Figure 3. Fluvial clay on a recent floodplain.

Figure 4. Silty loam soil on a recent terrace.

Figure 5. Spectral signatures of Kansas soils.



For purposes of economy, it is often advisable to reduce the number of data channels employed in processing. To determine which spectral channels are most useful, a digital program compares each signature with every other signature and determines which channels show the greatest differences between them. The ranking criterion is an input linear combination of pairwise distances. In other words, the best single channel for discriminating the soil samples is chosen first, then the channel that along with the best one is best, then the one that along with the chosen two is best, and so on. Statistically it is shown that the probabilities of misclassifying the various soils decrease with the addition of increasing numbers of data channels but that this change in misclassification probability declines very little after the best 5 or 6 channels have been selected (Fig. 6). The optimum 6 of the 10 channels were used in this study (Table 1).

COMPUTER RECOGNITION RESULTS

Ten training set areas were selected to represent the 6 major soil classes that characterize the Kansas test site: fluvial silt, fluvial silty loam, fluvial clay, clay derived from limestone, clay derived from shale, and clay derived from drift. Each of the training sets was a portion of a bare plowed field. The data were collected in early spring (1970) when as much as 50 percent of the agricultural fields were either freshly plowed (or disked) or had been plowed the previous fall. In other words, each training set signature was for the plowed soil of a cultivated field and was expected to be similar only to other plowed fields having the same kind of surface soil. No signatures were programmed for fallow fields or other nonbare soil areas. The objective was to classify soils in bare soil areas only. The recognition map results are shown in Figures 7 and 8.

Two types of error are inherent in computer-recognition maps of this sort. One type of error is a result of nonbare soil areas being classified by the computer as bare soil. The second type of error is a result of inadequate recognition of bare soil areas or areas classified as the wrong type of soil.

Analysis of the recognition results for the 15- by 1-mile data set indicates that few nonbare soil areas were incorrectly classified as bare soil. (Ground observations and color aerial photography collected at the same time as the multispectral scanner data helped establish the validity of the recognition results.) Several heavily wooded, north-facing slopes in the upland portion of the test site were spottily classified as upland clay soil. These areas were found to have accumulated as much as a foot of dead leaves from the previous fall (the trees were still bare) and had a reddish-brown appearance very similar to upland clay derived from drift.

The second type of recognition error was more serious than the first type. Of the approximately 1,100 acres of bare soil fields, 784 acres were automatically classified as one kind of soil or another. Of the classified areas, about 85 percent is considered to be correct recognition, based on landform and soil data supplied by the State Highway Commission of Kansas. Most of the incorrect classification came as a result of fluvial silty loam soil being classified as clay soil derived from shale. This misclassification is not surprising if one considers the close similarity of the signatures of these 2 soils (Figs. 1 and 2).

A marked difference between soil recognition in upland and relatively level floodplain and terrace areas occurred. In upland areas less than 50 percent of the bare fields was recognized, while almost 75 percent of the lowland soils was classified. This difference in recognition success is thought to be due to the nature of the bare fields in the upland areas. In general the fields were small and the soils were heterogeneous compared with the fluvial areas. Slope effects are thought to cause colluvial mixing of the several soils present and to effect the reflectance from these surfaces.

Soil surfaces, like most all natural objects, are not Lambertian (perfectly diffusing) reflectors. Sunlight incident on a soil surface is not reflected from that surface isotropically but is reflected rather differentially in different directions in relation to the incident angle of radiation and the nature and aspect of the reflecting surface. Also relative changes in reflectance with angle are wavelength dependent, being greater for

Figure 6. Average probabilities of misclassification of soils using from 1 to 10 data channels.

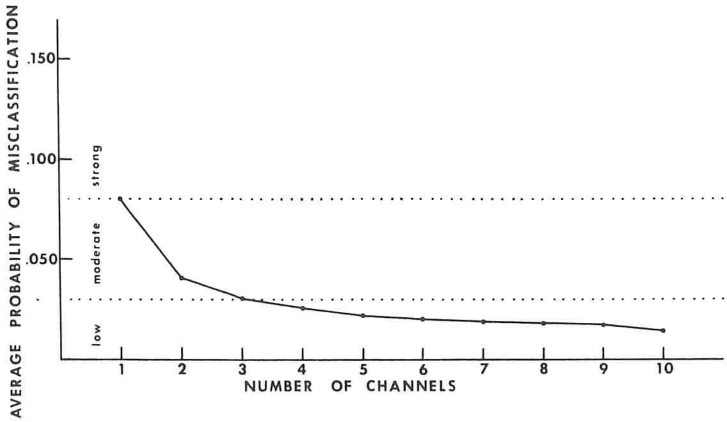


Figure 7. Multispectral soils recognition for Kansas River floodplain.

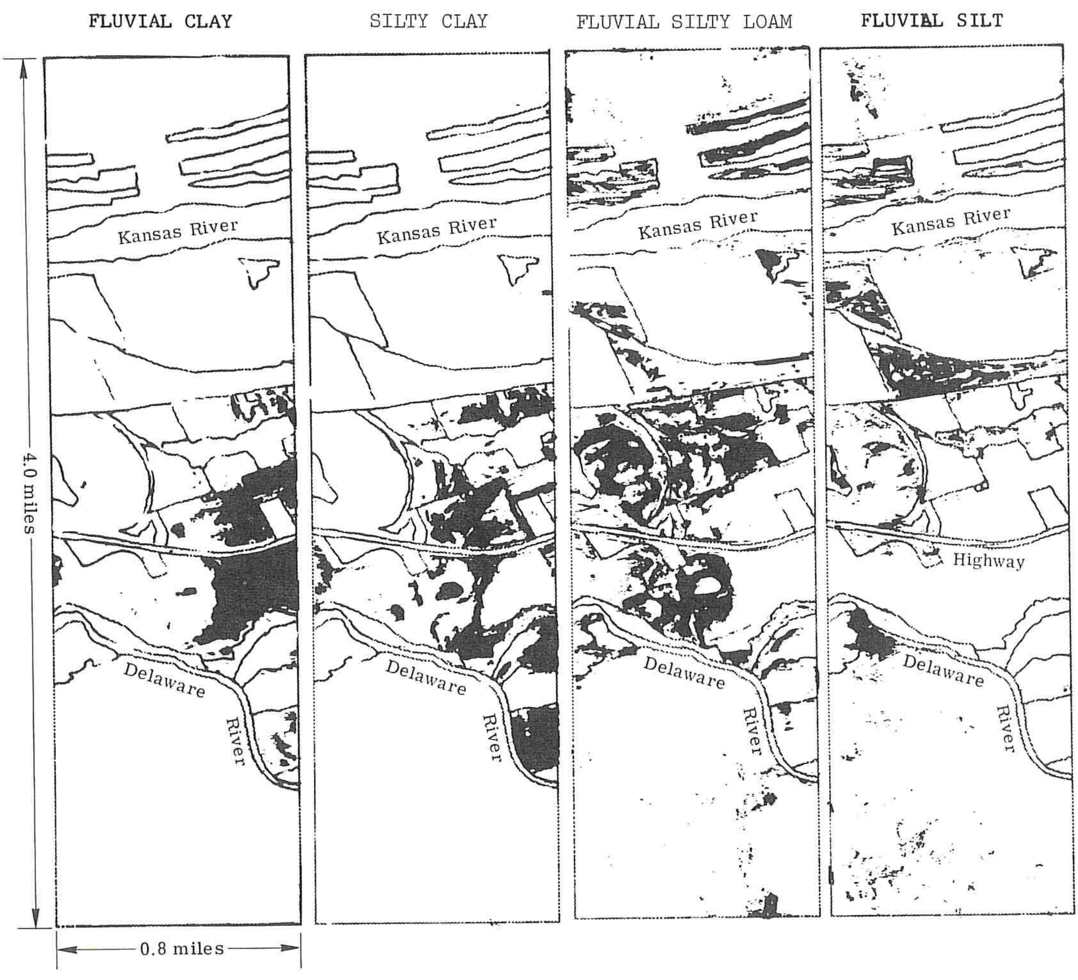


Figure 8. Multispectral soils recognition for Slough Creek floodplain area.

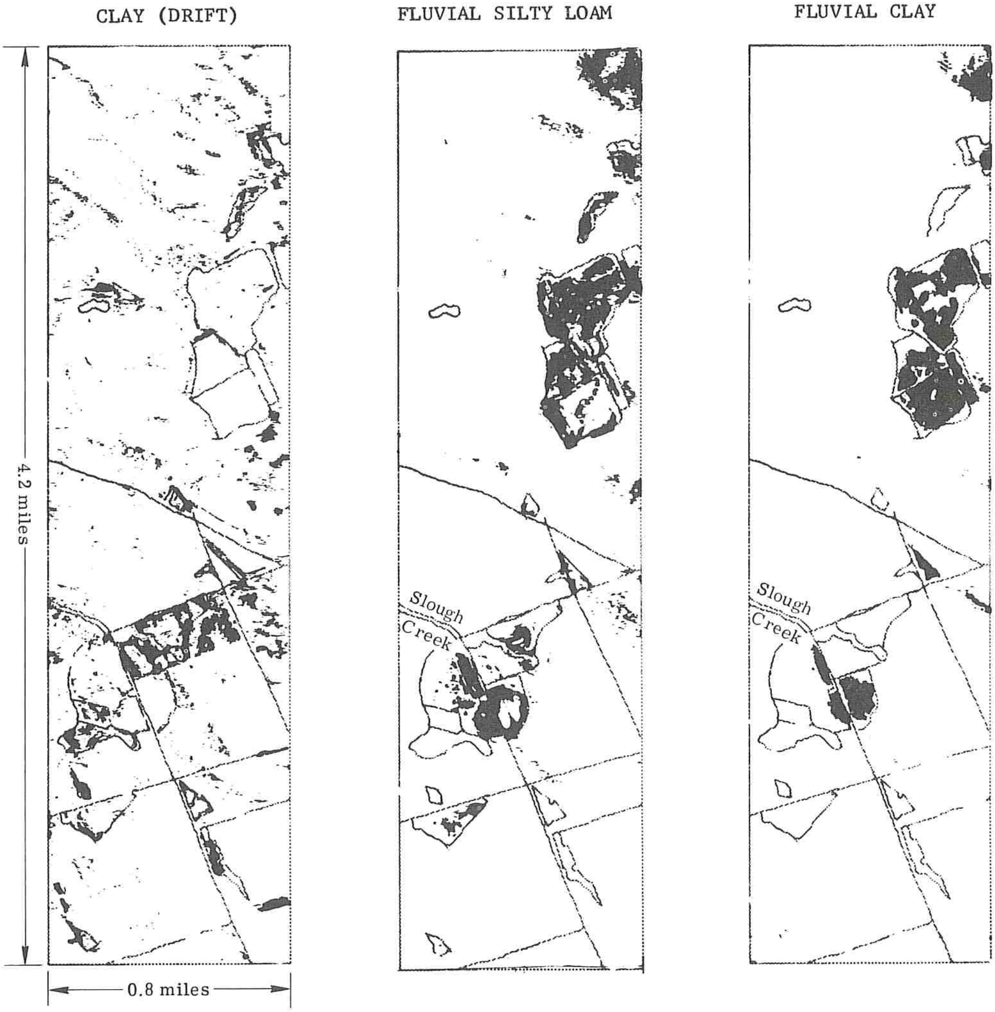
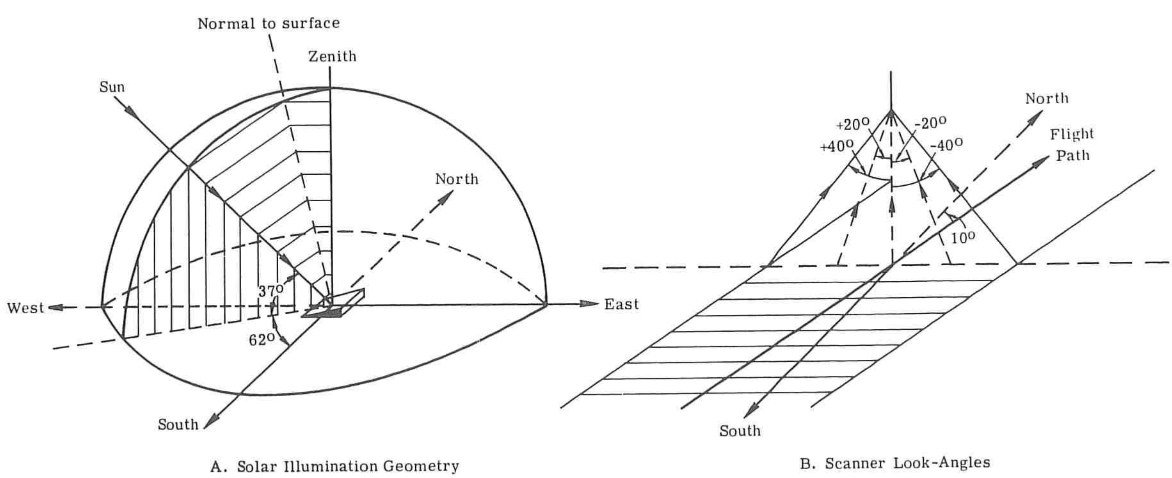


Figure 9. View-angle geometry for Kansas study site.



the shorter wavelengths than for longer wavelengths (3, 4). Figure 9 shows illumination geometry and variations in scanner view-angle geometry for this study site. Although no ground measurements were made to confirm this hypothesis, it is suggested that signatures established for several upland soils were affected by slope and scanner view-angle considerations. Signatures established for level fluvial areas were not adversely affected by slope and, thus, were applicable to the entire floodplain and terrace areas.

The recognition results for the Kansas River floodplain (Fig. 7) show the change from medium to heavy soil textures with increasing distance from the river. The change in texture closely corresponds to changes in landform, from floodplain veneer (silt deposits) to meander scars and minor terraces (silty loams) to older terrace deposits (clays). There appears to be a great deal of detail in surface variation as a result of historical meandering of a tributary, the Delaware River, across the Kansas River floodplain.

Good recognition results were achieved in the floodplain area of a small stream, Slough Creek, 12 miles north of the Kansas River (Fig. 8). Here, in addition to fluvial soils, the computer recognized small areas of clay derived from glacial drift on the floodplain. These small windows of clay were later found to be eroded areas occurring on the break in fluvial terraces. Apparently these terraces comprise reworked glacial drift, thus rendering the upland clay recognition where the subsoil is exposed to view (1).

SUMMARY

The results of this research indicate that useful and relatively accurate computer-recognition maps of soils may be developed through the use of multispectral data. There are, however, a number of important questions to be answered before this technique can become operational. Most fundamental is the question of precisely what soil parameters determine the spectral signature characteristics on which the computer-recognition results are based. In some cases, organic matter content of the surface may determine reflectance characteristics; in other cases it may be moisture, surface texture, mineral composition, or a combination of several or all of these. Second, at what level are surface spectral differences likely to delineate soil-mapping classes? Indications are that detailed soil delineations are available for bare areas in this way but that some ground observations are initially necessary to define the training sets and soil classes. What of nonbare soil areas? Signatures may be established for nonbare areas, and soils information can be inferred from the subsequent recognition maps in the same way that photo interpreters currently infer soil information from vegetation, landforms, rock outcrops, and land use—although this technique was not used in this study.

At the present state of the art, successful multispectral sensing of soils requires the following conditions: (a) the area to be surveyed should have a very large population of fields bare of vegetation at the time of the data collection flight; (b) data should be collected as near to solar noon as possible and in a direction parallel to the solar direction to minimize angle effects; (c) the terrain should be fairly level; and (d) some a priori soils information should be available for programming the computer.

ACKNOWLEDGMENTS

The author wishes to acknowledge the technical assistance of F. J. Thomson and P. G. Hasell, Jr., of Willow Run Laboratories and Harold T. Rib of the Federal Highway Administration for his support and kind encouragement.

REFERENCES

1. Stallard, A. H., and Biege, R. R. Personal communication. State Highway Commission of Kansas, Topeka.
2. Chapman, P. E., and Brennan, P. A. Albedo Curves for Major Soil Units, Variability Study. State Highway Commission of Kansas, unpublished rept., 1970.
3. Kondratiev, K. Y., Mironova, Z. F., and Otto, A. N. Spectral Albedo of Natural Surfaces. Jour. Geophysical Research, Vol. 59, 1964, pp. 207-216.
4. Coulson, K. L. Effects of Reflection Properties of Natural Surfaces in Aerial Reconnaissance. Applied Optics, Vol. 5, No. 6, 1966.

LONGITUDINAL TRAFFIC CONTROL BY INFRARED SENSING

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Two different types of infrared remote-sensing systems for longitudinal traffic control have been studied to prevent rear-end collisions and breakdowns in traffic flow and to improve the quality and capacity of traffic flow. A prototype of the infrared source-sensor has been built and tested in freeway driving, and some basic research on a self-contained infrared remote-sensing system was carried out. Because a control system of the car-following type has to restrict itself to vehicles in the same traffic lane, the problem of target identification in freeway traffic has also been researched. It appears that the present driver information system provided by traffic signs can be improved considerably by infrared sensing for the spacing of vehicles and by lane coding for continuous driver information and proper target identification. The source-sensor system has the disadvantage that all vehicles must be instrumented to make up an effective sensing system. The self-contained system can be introduced by leaving it to the individual driver whether he wants to spend money for equipment providing more safety and easier driving. If all vehicles could be joined in an infrared longitudinal control system, traffic capacity could be increased to about 4,000 vehicles/lane/hour at 40 mph on urban freeways.

•A CONSIDERABLE range of useful information could in principle be made available to the driver to increase traffic flow and to prevent accidents. Because rear-end collisions occur most frequently on urban freeways and expressways and because the stability of traffic flow is rather sensitive to disturbances in high-density traffic flow, remote-sensing systems were specifically studied for such traffic conditions. The broader context of the capability and the cost of competing systems was considered in the evaluation of the concepts and devices for remote sensing between vehicles. Sound, radio communication, and radar were studied as alternative systems before infrared was chosen as the most economic and promising remote-sensing system. Sound and ultrasonic devices were eliminated because of the broad spectrum of traffic noise and more specifically the exhaust noise of the reciprocating engine. Measurements would have to be made against a high level of background noise, and therefore the instruments for reliable sensing would be rather costly and complicated. Radar also is rather costly, and identifying the relevant target in freeway traffic poses a difficult problem. Another consideration was that the remote-sensing system must essentially be a vehicle-contained system and that auxiliary roadside equipment must be kept to an absolute minimum. This condition precluded the use of a radio-controlled remote-sensing system.

The criteria for the highway traffic sensing system were concluded to be as follows:

1. The system must be a longitudinal control system if the improvement of traffic safety on divided highways is a primary objective (on rural Ohio freeways rear-end or stopped or stopping vehicle accidents form 36.4 percent of all accidents, and on the John Lodge and Ford Expressways rear-end collisions form about 60 percent of the accidents);
2. The system must be a longitudinal control system, which aids the driver or operates automatically, if the velocity of vehicles is to be increased safely; and
3. The system basically must be a longitudinal control system with a range of at least 160 ft if increased traffic flow and the prevention of traffic jams are major objectives (lateral control to facilitate lane switching, however, must also be considered).

Two variations of the infrared sensing system were studied, and a prototype of the source-sensor system was built and tested in about 1,000 miles of freeway driving.

INFRARED SOURCE-SENSOR SYSTEM

The infrared source-sensor system makes use of a pulsed infrared light beam in the preceding vehicle; the pulse frequency is proportional to the lead car's velocity. The infrared source of the first version, a $4\frac{1}{2}$-in. sealed-beam lamp with a maximum rated initial candlepower of 35,000, was mounted at the rear of the lead vehicle pointing opposite to the direction of travel. The beam spread of the maximum intensity zone was 11 deg in a horizontal direction and $\pm 4\frac{1}{2}$ deg in a vertical direction. A Wratten 87C filter was used in front of the source, and the emission of visible light was so small that it was not possible to detect the source in daylight or nighttime freeway driving under field conditions. Sources of higher intensity and gallium arsenide lasers were considered. However, no extensive experiments have been carried out so far.

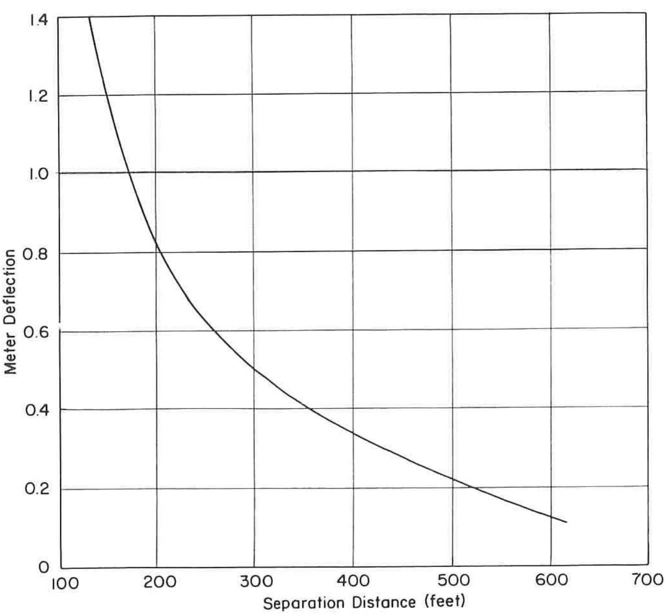
The pulsing of the source was provided by a rotating 3-bladed disk placed in front of the filter. This device kept the output of the source fairly constant because of a whipping and cleaning effect that prevented the accumulation of dirt and spray in adverse weather conditions. The 3-bladed disk was coupled to the output of a differential gear; one input was driven by a constant-speed motor, and a second input was coupled to the drive shaft of the automobile. The basic frequency supplied by the constant-speed motor served to identify the vehicle as a target and thus provided the necessary separation from other infrared sources like headlights of oncoming vehicles, advertising and traffic lights, or the low-standing sun. Through the second input of the moving vehicle via the drive shaft a speed-dependent chopping frequency was generated that was read by the sensor of the following vehicle. Most of the tests were carried out with a chopping rate from 40 to 130 pulses/second; that rate represented a speed range from 0 to 80 mph for the lead vehicle. Figure 1 shows the infrared source mounted in the rear of the experimental vehicle.

The sensor unit, shown in Figure 2, mounted under the front bumper of the following vehicle was designed to detect pulses emitted by the source of the lead vehicle and to convert this information to speed. The differential speed between the lead and the following vehicle was displayed on a meter. This output of the sensing equipment, however, can also be used to activate electrohydraulic elements for acceleration and braking control in an automatic longitudinal control system. Trailing vehicles can thus duplicate the acceleration pattern of leading vehicles with a delay of about 0.2 sec when spaced closely enough for the detector to lock on to the infrared source of the preceding vehicle. This distance was found to be about 400 ft for the prototypes tested in clear weather. As an additional safeguard, the intensity of the signal from the source of the preceding vehicle was also measured and was used to estimate the spacing between vehicles. Figure 3 shows a typical calibration curve for the distance-measuring circuit. The sensitivity, i.e., the change in deflection, is rather small at distances exceeding 250 ft. The system, however, becomes quite sensitive at distances below 250 ft, and at the critical spacings of high-density freeway traffic (about 50 ft) the system becomes very sensitive to changes in the distance to the leading vehicle. Figure 4 shows the traffic density and the average spacing of vehicles in freeway traffic for 4 operating regions. Because the intensity of the received signal is also a function of weather conditions, some adjustment of the sensing circuit is necessary to meet the safety requirement for driving in rain, fog, or snow. A driver, therefore, can adjust his instrument to warn him or to actuate the automatic deceleration system at a spacing he considers safe under the prevailing conditions. Although automatic adjustment to the prevailing weather condition would be highly desirable, no work has been done to develop any compensating instruments for changing weather conditions. It was found that weather conditions have a marked influence on the pulse-transmission characteristics at distances of more than 100 ft. At short distances this influence is somewhat reduced if a sufficiently strong source is used. The maximum range of the source system measured in a heavy snowstorm with stopped vehicles was about 900 ft.

Figure 1. Infrared source in preceding vehicle.

Figure 2. Detector mounted on following vehicle.

Figure 3. Calibration curve for distance measuring circuit.



The prototype of the source-sensor system needs further development. The most serious constraint is the fact that the system is not self-contained but requires a source in the lead vehicle and a sensing instrument in the following vehicle, and, for proper functioning of the longitudinal control system, all vehicles must be equipped with the necessary instrumentation. Furthermore, signals emitted by vehicles in adjacent traffic lanes can be picked up in curves, and they supply irritant information because the car-following control must be applied to vehicles in the same traffic lane only. The latter problem has been studied, and some research on traffic lane coding was carried out to avoid reaction to any irrelevant signals.

Thin metal stripes or metallic paint were used for lane coding to generate the communication code for a traffic lane. All vehicles in the same traffic lane can thus be tuned automatically to one communication language, and signals picked up from vehicles in adjacent traffic lanes will be ignored. Preliminary results suggest that specially designed metal detectors mounted on the underside of vehicles, preferably the rear axle of a car, can read the traffic lane code continuously from a moving vehicle. It is hoped that the lane-coding metallic paint pattern can be applied to traffic lanes with the help of existing lane-marking equipment. Another possibility is to attach a prefabricated plastic coding strip to the center of a traffic lane in a similar way as it is now done with plastic lane delineation stripes. Such a lane-coding system not only would facilitate the use of the longitudinal source-sensor control system but also could convey a multitude of information to the driver including messages that are now conveyed by traffic signs. It becomes increasingly difficult for drivers to perceive and react in time to traffic signs in high-density traffic flow. Forced lane changes, resulting in hazardous traffic situations, are quite frequently the result of the currently used freeway information system that hardly meets the requirements of high-density multilane urban freeway traffic. A passive lane-coding system will also have the advantage of low installation and maintenance costs in comparison with active highway information systems, such as roadside radio or computer-linked loop detectors. Tests also showed that the metallic coding stripe functions well with reinforced concrete roads because the coding stripe has a shielding effect and little background noise is picked up by the detector from the reinforcing steel.

SELF-CONTAINED INFRARED LONGITUDINAL CONTROL SYSTEM

Some research was carried out to develop a longitudinal control system that will give drivers the freedom of choice to equip their vehicle with an infrared sensing device that does not require any active equipment in other vehicles in sensing space and relative velocity between the lead and the following vehicle. The system works on the Doppler principle for distance measurement between successive vehicles in a traffic lane. A gallium arsenide source was used for the preliminary investigations. The performance of the system, however, was not satisfactory when the beam was reflected by conventional cat-eye reflectors from the rear of the leading motor vehicle. License plates designed like efficient corner reflectors were then used, and very encouraging results were obtained with this setup. Corner reflector license plates were chosen for the system because most of the states issue new plates every year and the introduction of efficiently designed reflectors for infrared sensing would thus not impose an unreasonable demand on the public. Furthermore, because license plates will be changed every year, it is expected that a good standard of the reflectors can be maintained and will make the system more reliable. Unfortunately, only a few stationary tests in adverse weather conditions were carried out with infrared equipment because of limited research funds. The results were encouraging, and it appears that the system can be developed to cover a range of 600 ft in fog. The background noise level in these first tests was high, and more powerful sources must be investigated before any decision on the design of the source can be made. So far a combination of gallium arsenide junction lasers seems to be the best choice.

ANTICIPATED SYSTEM PERFORMANCE

As stated previously, the infrared longitudinal control system has been developed to foster the following improvements in traffic flow: prevent rear-end collisions, prevent traffic jams, and increase traffic flow.

The evaluation of aerial photographs of freeway traffic shows that only about 60 percent of the drivers accept the safe car-following recommendation of one car length spacing per 10-mile increment in speed. Potentially unsafe conditions occur frequently if vehicles change traffic lanes. In studies of such situations, it was found that not only one car but also a number of vehicles can be involved in rear-end collisions under these conditions even if the driver is only forced to apply emergency braking. The most serious multiple rear-end collisions, however, were caused by fog patches drifting over a freeway that carries high-speed, high-density traffic. It is hoped that at least some of these accidents could be prevented by the infrared longitudinal sensing system, which can penetrate fog to some degree if the proper infrared window is chosen for the system.

A number of traffic experts have expressed their opinion that instability of traffic flow arises from the variance in response time of drivers to changes in the behavior of leading vehicles. Such "kinematic disturbances" are propagated and can lead to a breakdown in traffic flow, a condition that frequently occurs on urban freeways during peak-hour traffic. Here again, the infrared sensing system would provide a more uniform response to changes and thus reduce the generation and propagation of kinematic disturbances.

The efficiency of peak-hour urban freeway traffic is rather low, and freeway surveillance and control systems have been developed to improve the efficiency by controlling exits to freeways and restricting the traffic volume on the freeway to a load that is supposed to combine reasonable average speed with stability in traffic flow. Human efficiency in controlling vehicles in high-density traffic is not outstanding and can be improved by providing more and better information to drivers. A fully automatic longitudinal control system, however, will only be limited in its capacity by the response time of the electrohydraulic vehicle control system and by the requirements for stable traffic flow. An analysis of these conditions shows that, with a system response time of 0.2 sec and stable flow conditions, the capacity of a single freeway traffic lane can be increased to well over 4,000 vehicles/hour at 40 mph, as shown in Figure 5. Because the present maximum capacity for stable flow is about 2,000 vehicles/hour, the capacity of freeways can be doubled, leaving a very reasonable safety margin at 4,000 vehicles/hour/lane.

CONCLUSIONS

The techniques and instrumentation for infrared sensing have been developed to a high level during the past years, and applying this knowledge in infrared technology to highway traffic will definitely provide improvements in traffic safety and capacity. One of the most difficult problems of longitudinal sensing in highway traffic is to identify the proper target, i.e., the vehicle ahead in the same traffic lane. The source sensor system can very well be adapted to meet these requirements of automatic target identification by lane coding. The system should be very reliable, inexpensive, and easy to maintain in comparison with active coding systems. It also can be expanded to provide for other information displayed inside the vehicle and thus take over the function of traffic signs. The self-contained system is strictly a longitudinal sensing device that can be adapted to minimize errors in target identification at curves by having the source coupled to the steering system. This approach appears feasible, for properly designed freeways provide a sight distance commensurate with the design speed. However, more research is necessary, and the advantages or disadvantages of lock-on systems should be studied in more detail in field tests.

The range of infrared sensing appears to meet the requirements of freeway driving in adverse weather conditions, which is about 600 ft for a speed of 80 mph, though tests with reflectorized license plates are necessary.

Figure 4. Traffic density and mean spacing of vehicles at various speeds.

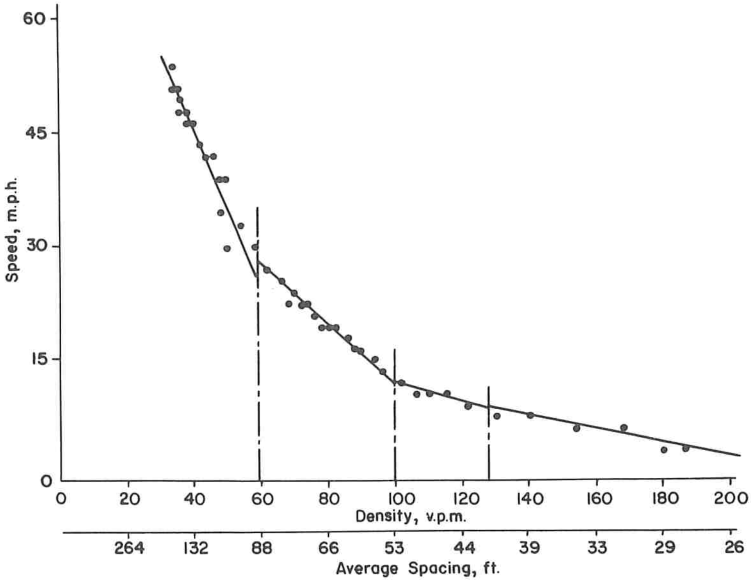
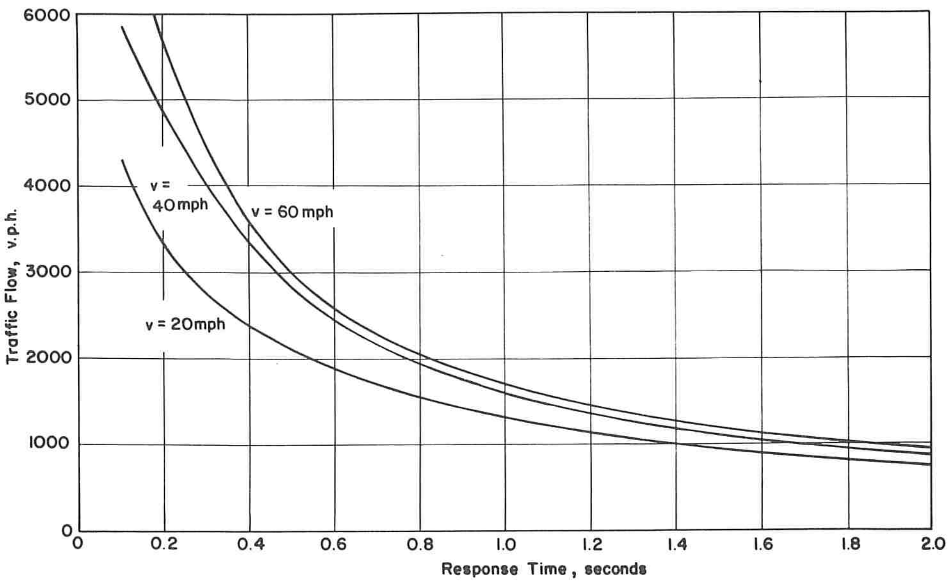


Figure 5. Traffic volume in relation to system response time for stable traffic flow.



The prototype of the source-sensor infrared sensing system was built for about \$120. The self-contained system will be more expensive, but costs are expected to remain reasonable for the service and additional safety that will be provided by the sensing device. It appears that infrared sensing for longitudinal traffic control has a definite cost advantage over other possible systems.

REFERENCES

1. Rockwell, T. H., and Treiterer, J. Sensing and Communication Between Vehicles. NCHRP Rept. 51, 1968.
2. Malo, A. F., and Mika, H. S. Accident Analysis of an Urban Expressway System. HRB Bull. 240, 1960, pp. 33-43.
3. Treiterer, J., and Nemeth, Z. A. Multiple Rear-End Collisions in Freeway Traffic, Their Causes and Their Avoidance. SAE Rept. 700085, 1970.
4. Treiterer, J., and Campbell, R. M. Control System for Automatic Vehicle Control. IEEE Automotive Conf., 1967.
5. Treiterer, J. Improvement of Traffic Flow and Safety by Longitudinal Control. Transportation Research, Vol. 1, 1967, pp. 231-251.

SEQUENTIAL AERIAL PHOTOGRAPHY AND IMAGERY FOR SOIL STUDIES

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Color infrared photographs from 6 dates during a 12-month period and thermal images from 4 times during a 19½-hour period are illustrated. The figures show agricultural fields located at the former shoreline of a small glacial lake. The contrast between the silty lake-bed soils and a small sandy beach ridge can be clearly seen. The contrast between this beach ridge and the surrounding lake-bed soils changes considerably during the year. The optimum time of the year for aerial photography for soil studies in southern Wisconsin is about May 1 to June 15. Based on the preliminary work reported here, it appears that thermal imagery has great potential use for soil-mapping purposes. There should be an optimum time of year and also an optimum time of day for obtaining thermal imagery for soil studies.

•THE INTERPRETIVE use of aerial photographs for soil studies may yield greatly varying results depending on the date on which the photographs were taken. The spectral response of objects and, therefore, the resulting air-photo patterns, vary greatly throughout the year. The tones and color values on photographs result primarily from differences in soil type, moisture content, and vegetative type and vigor. Some effects of date of photography, for which color and color infrared film were used, on air-photo interpretation have been previously illustrated by the author (1). A more detailed example of these effects will be presented here.

An example of significant differences in air-photo patterns in aerial photographs taken on different dates is shown in Figures 1 and 2. These photographs were purchased from the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture (USDA-ASCS). The figures show part of a glacial outwash plain in Rock County, Wisconsin, as photographed on panchromatic film on May 18, 1956 (Fig. 1) and on August 15, 1963 (Fig. 2). The striking braided pattern (A, Fig. 1) is a remnant from the time when glacial meltwaters flowed across the ground surface. The meltwaters were not competent to transport all soil and rock particles fed by the melting glacier and, thus, flowed with braided channels. Sand and gravel were deposited, forming this glacial outwash plain. The braided channels are slightly lower in elevation, are somewhat higher in soil moisture content, and have somewhat darker soils than the surrounding materials and thus photograph darker in tone. The braided pattern shown clearly in the May photograph is nearly obscured in the August photograph (A, Fig. 2) because of the vegetative cover (tall green corn). A few traces of the braided pattern can be seen at B in Figure 2, but the pattern is not so sharply defined as in Figure 1.

In an investigation of the effects of date of photography on air-photo patterns, photographs were taken on more than 30 different dates from May 1969 through September 1971 at selected sites in southern Wisconsin. Both color and color infrared 35-mm film were used. The results from 6 dates of photography at 1 site during a 12-month period are presented here. Selected sites were also imaged by a thermal scanner at 8 times during an 11-day period in September 1971. The results of 4 flights within a 19½-hour period at 1 site are also shown.

DESCRIPTION OF TEST SITE

USDA-ASCS aerial photographs of the test site, an area about ½ by ⅔ miles in extent, are shown in Figures 3 and 4. A landform map of the site is shown in Figure 5,

and a soil map is shown in Figure 6. Symbols used on the maps are defined as follows:

Item	Symbol
Landform	
Glacial lake bed (silty soil)	A
Younger beach ridge, el 920 ft (sandy soil)	B
Older beach ridge, el 925 ft (sandy soil)	C
Glacial lake bed (sandy soil)	D
Alluvial deposits (silty soil)	E
Made land (highway and industrial fill material)	F
Soil Name According to USDA-SCS	
Palms mucky peat	1
Maumee sandy loam	2
Rodman sandy loam	3
Washtenaw silt loam	4
Ossian silt loam	5
Made land	6

The test site is located a few miles west of Madison, Wisconsin, at the former shoreline of glacial Lake Middleton, an ephemeral glacial lake that is now primarily agricultural fields. This was a small lake, about 3 square miles in extent at its maximum. At its lowest level, the lake was only about 200 acres in size. The beach ridge associated with this lowest lake level is shown at B in Figure 5. The ridge is most distinct at the southeastern edge of the lake (shown here) because the prevailing winds at the time of its formation were from the northwest. It is a small feature, approximately 200 ft wide and only 2 or 3 ft higher than the surrounding lake-bed material. Figure 7 shows a ground photograph of a soil surveyor standing on the ridge while the photographer is standing on the lower lake-bed material. The beach ridge is difficult to notice on the ground and almost impossible to see in Figure 7 because of its small size. This paper will show that it can be clearly seen on aerial photographs taken at the proper time of year and also on thermal imagery.

Figure 6 shows a recent soil map of the area (compiled in about 1968 by USDA-SCS). Table 1 (4) gives typical soil profiles for the soils shown in Figure 6. The features to be emphasized in describing the photographs and thermal images will be the beach ridge shown at B and the surrounding lake-bed soils shown at A in Figure 5. As described by USDA-SCS, and confirmed by field observations, the beach ridge has a fine sandy loam surface soil about 12 to 18 in. thick underlain by deep sandy materials. The lake-bed soils to the left of this ridge are silt loam to a depth of at least 5 ft and are seasonally wet with a groundwater table within 2 ft of the ground surface in the early spring. The lake-bed soils between the ridge at B and the older ridge at C (Fig. 5) consist of silt loam to a 2- or 3-ft depth underlain by alternating layers of silt and fine sand and are also seasonally wet.

As the photographs contained in this report show, the location of the beach ridge is difficult to identify in some aerial photographs and relatively easy in others. For example, the ridge can be clearly seen in Figure 4 (June 4, 1968) but is more difficult to identify in Figure 3 (June 15, 1962). Two different soil scientists, using the 1962 USDA-ASCS photographs (Fig. 3) with selective field sampling, mapped parts of the area shown in Figure 6. The soil scientist mapping the lower two-thirds of the area shown in Figure 6 mapped the ridge as Maumee sandy loam. The soil scientist mapping the upper third of the area shown in Figure 6 was not able to identify the beach ridge and therefore mapped it, along with the rest of the lake-bed soils in the area, as Ossian silt loam. The resulting soil map (Fig. 6) shows the sandy soils on the beach ridge terminating about two-thirds of the way up from the bottom of the map. An analysis of the photographs and thermal images contained in this paper confirms that the ridge actually continues to the top of the map shown in Figure 6, as delineated in the landform map (Fig. 5).

Figure 1. Glacial outwash plain, panchromatic film, May 18, 1956.

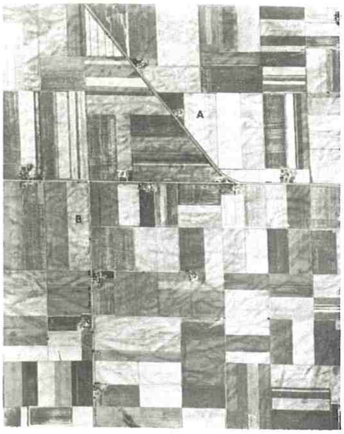

Figure 2. Glacial outwash plain, panchromatic film, August 15, 1963.

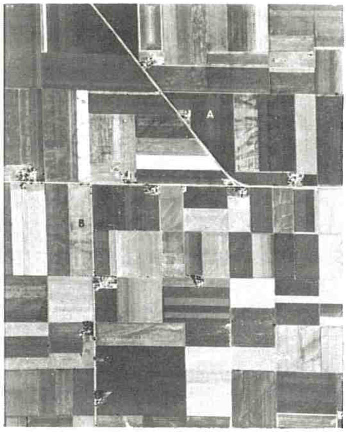

Figure 3. Test site, panchromatic film, June 15, 1962.

Figure 4. Test site, panchromatic film, June 4, 1968.

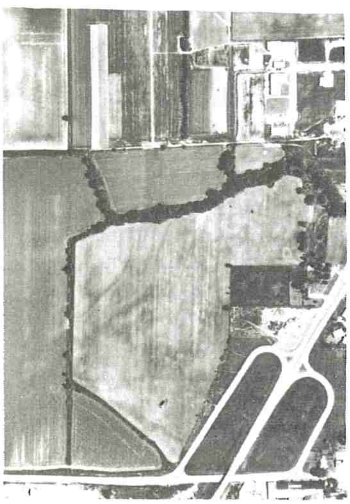

Figure 5. Landform map.

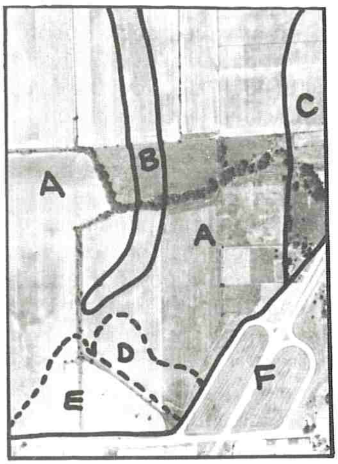

Figure 6. Soil map.

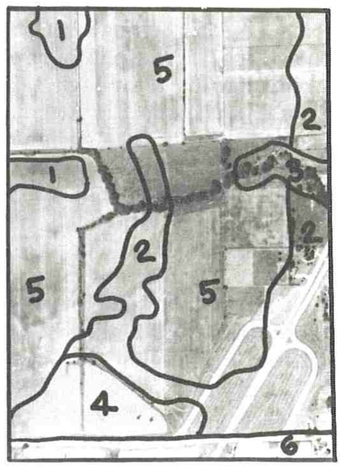

Table 1. Typical soil profiles of USCS soil classes.

Depth (in.)	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
0 to 12	Pt	SM	SM	ML-CL	ML-CL
12 to 30	Pt	SP	GW	ML-CL	CL
30 to 48	CL	SP	GW	CL	ML
48 to 60	SP	SP	GW	CL	ML

AERIAL PHOTOGRAPHY

Color and color infrared 35-mm photographs of the test site were taken on more than 30 dates during the period of May 1969 through September 1971. This paper contains 8 color infrared photographs taken on 7 dates during this time period. Figures 8 through 14 show oblique photos taken on a Minolta SRT-101 camera using Kodak Ektachrome infrared aero film, type 8443. Typical exposures were $\frac{1}{1000}$ sec at f/4.5 or f/5.6 in bright sunlight. Figure 15 shows a vertical photomosaic taken with a motor-driven Nikon F camera using Kodak Aerochrome infrared ESTAR base film, type 2443. It should be noted here that Kodak type 8443 color infrared film, used for many years by various investigators in both aerial format and 35-mm cassettes, is no longer available. It has been replaced by Kodak type 2443 film (available as aerial film and also as 35-mm bulk film upon special order) and Kodak type 2236 film (also known as Ektachrome infrared film, IE 135-20, available in 35-mm cassettes). The new type 2443 film appears to have about the same spectral sensitivity as the type 8443 film. This investigator has had poor results with type 2236 film in 35-mm cassettes and cannot recommend its use as a replacement for type 8443 film. Investigators are advised to purchase type 2443 film in bulk 35-mm format in order to achieve results that can be compared with aerial photographs on type 2443 film or with existing photographs on type 8443 film.

Although the originals to Figures 7 through 15 are in color and color infrared, these illustrations are reproduced here in black and white. (A complete set of 2 by 2 slides of all 20 illustrations contained in this paper, including Figures 7 through 15 in color, is available and can be purchased for $10 from Ralph W. Kiefer, 2210 Engineering Building, University of Wisconsin, Madison, Wisconsin 53706.)

SEQUENTIAL COLOR INFRARED AERIAL PHOTOGRAPHY

Figure 8 shows an oblique color infrared aerial photograph of an area about 1 mile square. This photograph was taken on July 29, 1971, as was Figure 10. Figures 3 through 6, 9 through 14, and 17 through 20 show the area shown in the lower right corner of Figure 8. Although it cannot be seen clearly in Figure 8, the entire former shoreline of the lowest level of glacial Lake Middleton lies within the area shown in this photograph. Most of the former shoreline can be clearly seen in Figure 16, a thermal image that will be described later.

Figures 9 through 14 show color infrared photographs taken on 6 dates within a 12-month period. They were selected from a group of photographs taken by the author on about 30 different dates during a 14-month period, and they illustrate the great changes in air-photo patterns that can occur at different times during the year. The Lake Middleton beach ridge (B, Fig. 5) is clearly visible in the upper left corner of the plowed field in the June 28 photograph (Fig. 9). This ridge is virtually impossible to locate in the July 29 photograph (Fig. 10) because of similar reflectance characteristics of the healthy corn leaves both on and off the ridge. Bare soil cannot be seen in this field because of the dense cover of tall green corn. A careful inspection of the August 11 photograph (Fig. 11) will show that the beach ridge is just barely visible. Without knowing in advance its location, an interpreter might not notice its presence. The location of the ridge is clearly revealed in the September 3 photograph (Fig. 12) because of the difference in green, red, and infrared reflectance of corn leaves on and off the ridge. Because of dry soil moisture conditions on the sandy beach ridge soil, the corn planted on the beach ridge has withered and the leaves have turned brown. The corn on the silty lake-bed soils with a higher moisture content still has healthy green leaves.

Figure 13 shows the ridge the next spring (May 28, 1970). Here, more infrared energy is reflected by the vegetation on the ridge than by the vegetation on the silty lake-bed soils. This is because in the spring the sandy beach ridge soils are warmer than the wetter silty lake-bed soils and, thus, the crop (peas) is growing more vigorously on the beach ridge. Figure 14 (June 29) shows the same area just after it has been plowed and planted in corn. The tones are similar to those shown in Figure 9, taken almost exactly 1 year previously, and are primarily a function of the soil moisture conditions, for the field was recently plowed and there is essentially no vegetation.

Figure 7. Soil survey on beach ridge, color film, June 29, 1970.

Figure 8. Test site, color infrared film, July 29, 1969.

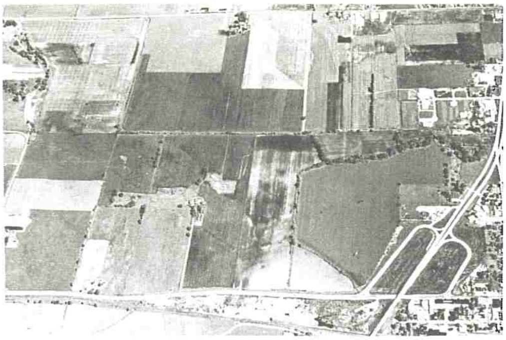

Figure 9. Test site, color infrared film, June 28, 1969.

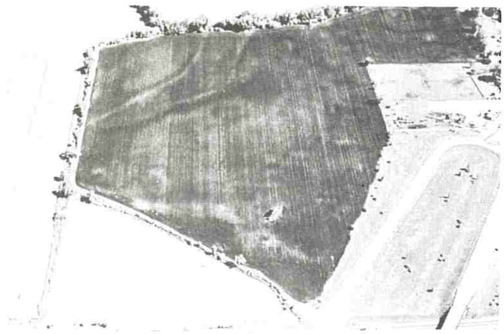

Figure 10. Test site, color infrared film, July 29, 1969.

Figure 11. Test site, color infrared film, August 11, 1969.

Figure 12. Test site, color infrared film, September 3, 1969.

Figure 13. Test site, color infrared film, May 28, 1970.

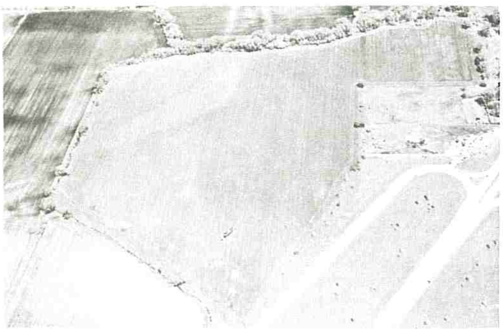

Figure 14. Test site, color infrared film, June 29, 1970.

In the previously mentioned paper by the author (1) is shown the striking tonal contrast related to corn vigor on different soils in the field located at the extreme left edge of the area shown in Figure 8. In that paper are also shown the striking changes in tonal patterns that can occur from one day to the next as bare soils dry out after a rainfall.

Figures 9 through 14 are intended to show the nature of the changes in air-photo patterns that can take place throughout the year. The patterns seen on these photographs are primarily functions of the soil type, soil moisture conditions, and, within any one crop, vigor of vegetation. The principal variable is soil type, for the soil moisture and vegetation vigor vary with the soil type. Therefore, the different patterns shown in Figures 9 through 14, especially the pattern caused by the beach ridge, are primarily the result of different soil types. These figures show that certain dates of photography are better than others for distinguishing among different soil types. For southern Wisconsin, the optimum time of the year for aerial photography for soil studies appears to be May 1 to June 15; the period from September 1 to 30 is excellent under certain conditions.

Persons using available ASCS photographs for interpretive work may find that the most recent date of photography is not necessarily the optimum time of year and should inspect several sets of available photographs to select the optimum set. Those wishing to contract for aerial photographic work for interpretive purposes should consider carefully the time of year acceptable to them for aerial photography.

If photographs on several dates are available, then there should be some advantage in comparing the air-photo patterns at several times during the year. The NASA-ERTS satellite, which has orbited the earth since mid-1972, sends back images of each part of the mainland United States once each 18 days. A temporal analysis of these data should reveal considerably more information than can be obtained from imagery on just one date.

THERMAL IMAGERY

Thermal imagery was obtained for the test site 8 different times during an 11-day period in September 1971. Color and color infrared photographs were also taken during the 4 daytime missions.

The thermal images were obtained with the support of the National Center for Atmospheric Research; a Texas Instruments RS-310 airborne infrared mapping system was used. Texas Instruments (2) describes the scanner as follows:

> The RS-310 is a passive, airborne infrared imaging system that scans the ground along and to both sides of the flight path and produces a continuous image of the scanned terrain. Energy is received by the scanner from the ground, focused on cyrogenic-cooled detectors, converted to light through the use of a light-emitting diode, and by means of a mechanically-coupled recorder exposes the photographic film in the film magazine. The film is moved at a rate proportional to the velocity and height of the aircraft, producing the continuous photographic record of the radiant energy detected.

The basic characteristics of infrared radiation, atmospheric transmission, and infrared detection and recording have been described in several papers in an HRB special report and will not be repeated here.

The specific characteristics of the scanner, detector, and flight parameters, as used for the 4 flights described here, were as follows:

Characteristic	Value
Detector sensitivity, μm wavelength	8 to 14
Spatial resolution, milliradian	5
Flight height, ft above terrain	2,000
Aircraft velocity, mph	150
Scanner field of view, deg	90

Figure 15. Test site, color infrared film, 10:00 a.m., September 18, 1971.

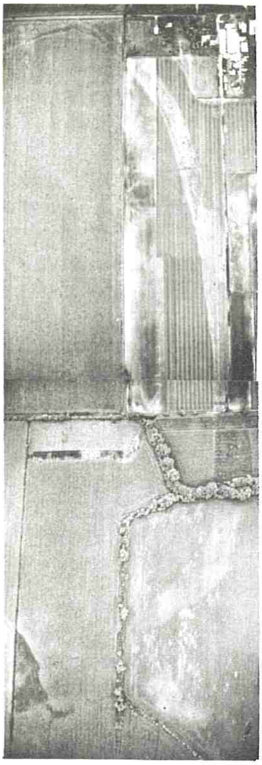

Figure 17. Test site, thermal image, 2:30 p.m., September 17, 1971.

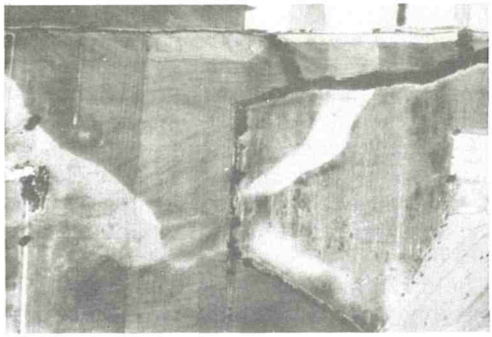

Figure 18. Test site, thermal image, 10:00 p.m., September 17, 1971.

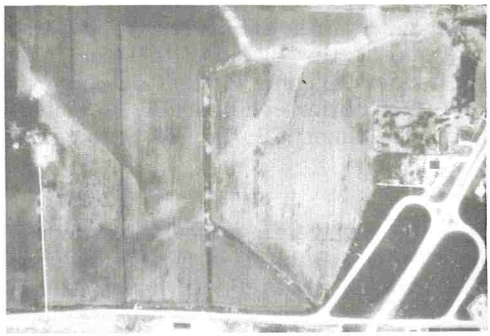

Figure 16. Test site, thermal image, 10:00 a.m., September 18, 1971 (same area as in Fig. 15).

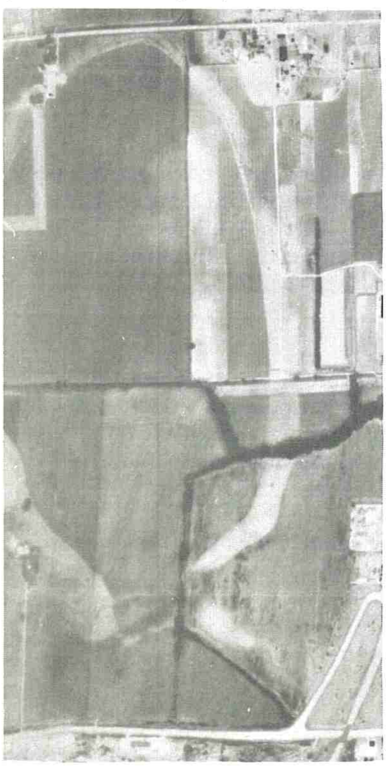

Figure 19. Test site, thermal image, 2:00 a.m., September 18, 1971.

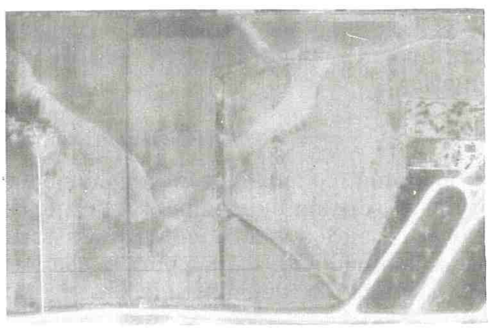

Figure 20. Test site, thermal image, 10.00 a.m., September 18, 1971.

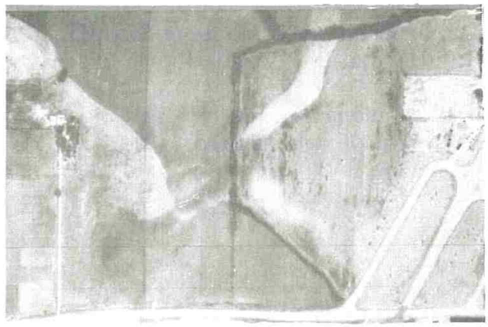

Figure 15 shows a color infrared photomosaic taken at the same time as the thermal image shown in Figure 16. Figures 17 through 20 show the same area at 4 different times during the 19½-hour period from 2:30 p.m. to 10:00 a.m. In all figures shown here, the darker toned areas represent the cooler temperatures, and the lighter toned areas represent the warmer temperatures.

The thermal scanner can resolve small differences in apparent temperature of natural objects. The apparent temperature on the beach ridge shown in Figure 20 is about 61 F, whereas the apparent temperature on the silty lake-bed soils to either side of the ridge is about 56 F.

Based on field radiometric measurements with a PRT-5 radiometer and an analysis of the thermal imagery, it was determined that apparent temperature differences as small as 2 F can be distinguished on the thermal imagery.

It appears that the use of thermal imagery interpretation has great potential for soil studies. Figure 16 shows a very clear image of the former shoreline of the last stand of glacial Lake Middleton. The warmer sandy ridge can be readily distinguished from the cooler silty lake-bed soils because of the difference in gray tone on the image.

Thermal contrast is greatest during the daytime flights (Figs. 17 and 20) because of differential thermal heating by solar radiation. Analysis of these images is still in progress, and further imagery for soil studies can be ascertained. The maximum amount of soils information can probably be obtained by a comparison of thermal images from 2 or more times during a 24-hour period.

SUMMARY

The nature of the changes in air-photo patterns that occur on photographs taken on different dates has been illustrated in this paper. These changes are related to soil type, moisture content, and vigor of vegetation. An analysis of aerial photographs taken at different dates during the year shows that there is an optimum time during the year for procuring aerial photographs for interpretive use for soil studies. In southern Wisconsin, the optimum time of the year appears to be May 1 to June 15; the period of September 1 to 30 is also very good. A comparison of images from several times during the year, such as those from the NASA-ERTS satellite, should yield more information than images from a single date of photography.

Thermal imagery from several different times of day was illustrated in this paper. Aerial thermal imagery appears to have great potential use for the purpose of soil mapping and evaluation.

ACKNOWLEDGMENTS

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REFERENCES

1. Kiefer, R. W. Effects of Date of Photography on Airphoto Interpretation Using Color and Color-Infrared Films. In 1970 International Symposium on Photography and Navigation (Ghosh, S. K., ed.), Internat. Society of Photogrammetry, Dec. 1970.
2. RS-310 Airborne Infrared Mapping System. Texas Instruments, Inc., Dallas.
3. Remote Sensing and Its Application to Highway Engineering. HRB Spec. Rept. 102, 1969.
4. Dane County, Wisconsin, Interim Soil Survey Report. Soil Conservation Service, U.S. Department of Agriculture, 1971.

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